

SPACE ENVIRONMENT STEERING GROUP (SESG)

RESULTS OF TASK 2

FOR THE

**NATIONAL POLAR-ORBITING OPERATIONAL
ENVIRONMENTAL SATELLITE SYSTEM
(NPOESS)**

Prepared by

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1. DOCUMENT SCOPE

This document represents the final results of Task 2 for the Space Environment Steering Group (SESG). The results of Task 2 are a re-validated and revised list of Environmental Data Records (EDRs) for space environmental sensing by the NPOESS. The final products are provided to the NPOESS Joint Agency Requirements Group (JARG) and, subsequently, to the NPOESS Senior Users Advisory Group (SUAG), for their consideration and approval. These products directly affect the scope of and the specifications for the NPOESS Space Environment Sensor Suite (SESS) which will be detailed in the SESS Sensor Requirements Document (SRD) as a part of Task 3 for the SESG.

1.1. Overview of the SESS

The SESS is the complement of sensors and algorithms used to provide the Space Environmental Parameters as specified in the NPOESS Integrated Operational Requirements Document (IORD) I. These data provide information about the space environment necessary *to ensure* reliable operations of current space-based and ground-based systems, *to facilitate* the analysis of system anomalies that may be the result of space environmental effects, and *to guide* the design and efficient operations of future systems that may be affected by the space environment. General aspects of the space environment known to be important to these activities include; 1) thermospheric densities, temperatures, and composition, 2) ionospheric densities, temperatures, and ion composition and electron-ion bulk motions, 3) energetic charged particle fluxes extending from suprathermal to high energies, and 4) solar and magnetospheric energy inputs that couple to the thermosphere and ionosphere. Within the context of this report the

processed Space Environmental Parameters are referred to as the space Environmental Data Records (EDRs).

1.3 Document Overview

The final products for consideration by the JARG and SUAG are summarized in Section 5 of this document. Other sections of this document provide justification and background for the final products. The following section provides the background for the SESG and the 3-phased tasking which has resulted in this submission. As noted above, the scope of this document is limited to Task 2 as a re-validation and consideration of the space EDRs. However to place these results in context, Section 3 provides a brief review of Task 1 efforts which were to quantify user needs. Section 4 is a description of Task 2 activities by the working groups that were formed to address the related areas for; 1) ionospheric effects, 2) satellite drag, and 3) satellite design and anomaly resolution. The final products in Section 5 were derived from these three working groups. Conclusions and appendices, as needed, follow.

2. BACKGROUND

The SESG was formed in late FY96 with the mission to provide cost-effective solutions to the IPO for acquiring the NPOESS Space Environmental Sensor Suite (SESS). On February 18, 1997 the SESG was directed by the Associate Director for Acquisition (ADA) of the NPOESS Integrated Program Office (IPO) to “study the space environmental sensor (SES) user applications, prioritize the SES requirements, and to recommend a sensor suite which will satisfy the required NPOESS SES EDRs.” The SESG recognizes that NPOESS plays only a part in the whole space environmental support structure and that a variety of data sources are required to satisfy user needs. The

three tasks assigned to the SESG by direction of the ADA were to; 1) assess user needs for space environmental data products, 2) validate the set of space EDRs assigned to the NPOESS, and 3) develop the SESS SRD for the ADA. Figure 1 shows the structure for the SESG and the assigned OPRs for the different task. A more detailed description of these tasks and expected output products is provided below.

2.1. Task 1: Assessment of User Needs

The purpose of this assessment was to critically evaluate user needs for space environmental data within the context of a potentially affected system. Such systems may operate either within space (satellites), through space (radar), or coupled to space (power grids). As defined here, the “user” is not considered to be a service provider such as the DoD 55th Space Weather Squadron (55 SWXS) or the NOAA Space Environment Center (SEC) but, rather, the end user or system administrator. For example, civilian power

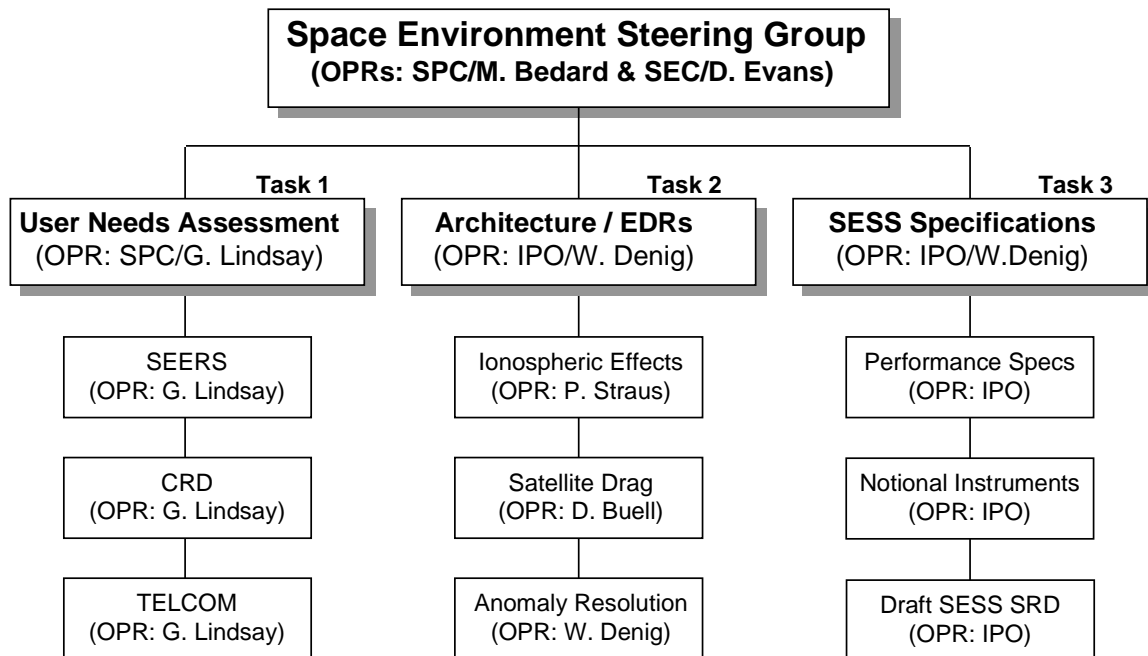


Figure 1. SESG Outline.

utilities, as the end users, require knowledge of geomagnetic storm conditions that can have adverse effects on local and distributed electric power grids. For the NPOESS, the applicable user needs are those specified by the DoD, the DoC, and NASA. Within the context of this understanding the following sub-tasks for the SESG were specified:

- Develop a list of the users of space environmental data within the military and civilian communities,
- Assess mission impacts and sensitivities to the space environment,
- Detail whether current space environmental data products are used directly or as inputs to models whose outputs are subsequently used,
- Survey user satisfaction with space environmental data products currently available and expectations for future products

The output product for Task 1 is a documented list of user needs for space environmental data products. The Offices of Primary Responsibility (OPRs) for these output products are the NOAA Headquarters and the Air Force Space Command/DRF.

2.2. Task 2: EDRs Specification and Validation

The results of Task 1 define that set of space environmental data products and services that must be supplied to the end users by the Space Environmental Support Architecture (SESA). This architecture includes both the space environment Data Centrals; that is, the SWXS and the SEC, and tactical users. The SESA includes all the resources and facilities needed to collect, process, and disseminate space environmental data products and services. The Data Centrals require input data from a variety of sources which include NPOESS and other space-based and ground-based space environmental sensing platforms. Task 2 must consider the entire SESA and determine those space

EDRs for which an NPOESS solution, in the balance, is the most cost effective and reliable. The sub-tasks for Task 2 are:

- Document existing Concept of Operations (CONOPS) within the SESA to satisfy user needs for space environmental products,
- Identify changes to existing CONOPS that will improve user support within a revised SESA,
- Determine which space environmental products in the revised SESA should be allocated to the NPOESS and are consistent with the NPOESS Integrated Operational Requirements Document (IORD) I,
- Identify which, if any, of the current NPOESS space EDRs can be better met by other space and ground sensing platforms

The primary output product of Task 2 is a re-validated and revised list of EDRs for space environmental sensing by the NPOESS. The OPR for the output of Task 2; that is, this report, is the NPOESS ADA. This report is submitted to the NPOESS JARG for their consideration and action.

2.3 Task 3: SESS Recommendations

Input to this task is the approved list of NPOESS space EDRs from Task 2.

Performance level specifications for the component sensors must be identified and justification established for those specifications driving or limiting instrument performance. Sensor recommendations should also take into account the accommodation and budgetary constraints of the NPOESS. As a secondary effort, existing or emerging instrument designs and concepts for achieving the required level of performance should

be identified along with technology maturity indicators and Rough-Order of Magnitude (ROM) costs. Task 3 has the following sub-tasks:

- Develop SESS performance specifications within a draft SESS SRD,
- Recommend SESS architectural alternatives consistent with NPOESS budgetary constraints,
- Develop a draft Briefing To Industry (BTI) on the NPOESS SESS requirements

The primary output products of Task 3 are a draft SESS SRD for consideration and a draft BTI on the SESS requirements. The OPR for outputs of Task 3 is the ADA.

3. REVIEW OF TASK 1

The purpose of Task 1 for the SESG was to identify and validate user needs for space environmental support. As noted earlier, user needs originate or are validated by the DoD, the DoC, or NASA. For the purposes of this task, user needs for space environmental support were initially identified by a survey of existing military and civilian requirements and the users of space environmental products. The SESG has been a leveraged activity capitalizing on the increased interest in space environment effects due, in part, to the rising solar activity of the 11-year solar cycle which will peak around March of 2000. In November 1997 the Space Environmental Exploitation Requirements Seminar (SEERS), sponsored by the Air Force Space Command (AFSPC), brought together users and providers of space environmental data for both the military and civilian sectors. While the focus of the SEERS was the DoD, this meeting has been followed by a series of meeting on the “Hazards of Space Weather” sponsored jointly by the AF Research Laboratory (AFRL) and the SEC to address both military and civilian needs. These meetings have been followed by fact-finding missions and extensive telephone

<u>USER: DOD</u>	<u>USER NEED</u>
Radar Operations	Solar noise and auroral clutter specification
	Range error correction, Scintillation
HF Communications	MUF/FOT, PCA event, Shortwave fades
Navigation/Satellite Communications	Single frequency GPS accuracy
	Scintillation forecast/specification
Classified	Arbitrary slant path TEC
Altimetry, Single Frequency	Ionospheric corrections for sea surface heights
Satellite Design and Anomaly Analysis	Radiation hazards for manned spaceflight & high flyers
	Long-term representative data sets for satellite design
	Space environment data for anomaly resolution
Space Surveillance	Accurate neutral density forecast/specification

<u>USER: DOC</u>	<u>USER NEED</u>
Satellite Operators	Space environmental parameters affecting satellite ops
Power Companies	Distribution and intensity of geomagnetic field variations
NASA	Radiation dose(man) , polar cap boundary, satellite drag
FAA	Ionospheric impacts on communications and navigation
NOAA	Radiation effects on satellite, mag field variations, drag
Ham Radio Operators	Global ionospheric disturbances
Geo-Prospecting	Locations of geomagnetic field variations
Science Community	Space environment effects on experiments, contamination
International Forecast Cntrs (Japan, Australia, etc)	Global situational awareness

<u>USER: NASA</u>	<u>USER NEED</u>
Manned Spaceflight	Radiation Dose
Satellite Lifetimes	Orbital drag forecasts

Figure 2. Summary of User Needs for Space Environmental Data.

surveys to validate user needs. For the DoD this has resulted in the AFSPC Capstone Requirements Document (CRD), currently in draft form, for the Space Environment Mission Area (SEMA). No similar such document exists for the NOAA.

A summary of the validated user needs for space environmental data is provided in Figure 2. You will note that these needs extend across a wide spectrum of applications both within the military (DoD) and civilian (DoC and NASA) sectors. The user needs also vary from very specific needs; for example, radiation dose for manned spaceflight, to quite general needs; for example, space environmental data for satellite anomaly assessments. What is apparent, however, is that there is a natural grouping for these space environmental needs into requirements for data products related to solar

observations, the ionosphere, the thermosphere, and energetic charged particles in the geospace.

4. TASK 2 WORKING GROUP REPORTS

The space EDRs for the NPOESS satisfy user needs for assessing near-earth space effects on military and civilian systems. In order to better evaluate NPOESS' contribution in addressing user needs, we divided these effects into three distinct categories related to; 1) the ionosphere, 2) the neutral atmosphere, and 3) energetic charged particles and assigned responsibility for each category to a separate working group. Ionospheric impacts are perhaps the most widespread affecting a large number of users; for example, communications, navigation and geo-positioning, radars, and power distribution. The neutral atmosphere is responsible for satellite drag on satellites in low earth orbit. Space radiation from energetic charged particles affect satellite operations and limit satellite lifetimes. Space radiation is also an issue for manned spaceflight. The AFSPC/DRF (Maj. Bedard) has indicated to the SESSG that, in general, the DoD priority

-Working Group 1- Ionospheric Effects & Scintillation	-Working Group 2- Satellite Drag & Neutral Density	-Working Group 3- Satellite Design & Anomaly Resolution
Paul Straus, Aerospace (Lead) Gretchen Lindsay, Aerospace (Co) Dave Anderson, AFRL Santi Basu, AFRL Greg Bishop, AFRL Terry Bullett, AFRL Ken Davies, NOAA/SEC Dave Evans, NOAA/SEC Joe Kunches, NOAA/SEC Pat Lunney, 76SOPS Bob Meier, NRL Ed Weber, AFRL Brian Wilson, JPL	Diane Buell, IPO/MITRE (Lead) Tim Fuller-Rowell, NOAA/SEC Frank Marcos, AFRL Jerry Owens, NASA/MSFC Mike Picone, NRL Mark Storz, AFSC/SWC Richard Walterscheid, Aerospace	Bill Denig, IPO (Lead) Phil Anderson, Aerospace Steve Cahanin, 50 WS/DO Dave Evans, NOAA/SEC Harry Koons, Aerospace Gary Mullen, AFRL Steve Pearson, NASA/MSFC Dave Speich, NOAA/SEC Michelle Thomsen, LANL

Figure 3. List of Participants for the Working Groups

for these categories is in the order indicated; that is, the ionosphere being the most important. The DOC makes no such distinction.

Figure 3 lists the participants and their organizational affiliation for each of the three working groups. The working groups consisted of government experts from a wide spectrum of government agencies representing users, service providers, and researchers. The working groups were tasked to evaluate those NPOESS space EDRs which applied to their mission area. While there was considerable overlap in the EDRs that affected the different mission areas it was decided that each working group would be assigned, as primary, those EDRs that were best aligned to their respective mission areas. See Table 1 for the complete list of NPOESS space EDRs and the working group assignments. The working groups met at various times during the Spring and Summer of 1997 and thereafter communicated either by telephone or e-mail.

SPACE EDRs	IORD-1	WG1	WG2	WG3
Auroral Boundary	4.1.6.7.1	X		
Auroral Energy Deposition, Total	4.1.6.7.2	X		
Auroral Imagery	4.1.6.7.3	X		
Electric Field	4.1.6.7.4	X		
Electron Density Profiles/Ionospheric Specification	4.1.6.7.5	X		
Geomagnetic Field	4.1.6.7.6			X
In-situ Ion Drift Velocity	4.1.6.7.7	X		
In-situ Plasma Density	4.1.6.7.8	X		
In-situ Plasma Fluctuations	4.1.6.7.9	X		
In-situ Plasma Temperature	4.1.6.7.10	X		
Ionospheric Scintillation	4.1.6.7.11	X		
Neutral Density Profile/Neutral Atmospheric Specification	4.1.6.7.12		X	
Radiation Belt and Low Energy Solar Particles	4.1.6.7.13			X
Solar and Galactic Cosmic Ray Particles	4.1.6.7.14			X
Solar Extreme Ultra Violet Flux	4.1.6.7.15	X		
Supra-thermal through Auroral Energy Particles.	4.1.6.7.16			X
Upper Atmospheric Airglow	4.1.6.7.17	X		

Table 1. Space EDRs assigned to each Working Group.

The reports for the three working groups follow. These reports summarize the finding of the groups. The full and final out-brief products for the working groups are contained in the appendix. The integrated product for the combined working group reports is summarized in the section 5.

4.1 Ionospheric Effects and Scintillation Working Group

Three basic tasks were assigned to the each of the working groups. These tasks were to; 1) assess current and future CONOPS for meeting operational needs for space environmental data in the working group's focus area, in this case the ionosphere, 2) evaluate the role NPOESS will play in future CONOPS and 3) review the NPOESS space EDRs and recommend changes, as needed. The ionospheric group's analysis has resulted in a clearer understanding of the requirements traceability from the end user to the NPOESS space EDRs. This understanding was the basis of the EDR prioritization which the working group recommended. In all, the group recommended the deletion or merging of three EDRs (in-situ drift velocity, in-situ plasma density, upper atmospheric airglow) and creation of one new EDR (neutral winds). Fairly significant changes were recommended for the attributes of two EDRs (electron density profile and auroral imagery) along with a number of minor changes to several other EDR attributes.

4.1.1 *User Needs Assessment*

Multiple DoD operational systems are affected by the Earth's ionosphere. The DoD systems reviewed by this group were radars, satellite communication and navigation systems (including GPS), HF communications systems, satellite altimeters for ocean wave heights, and National Programs. The working group's analysis found, however, that not all of these "system needs" for ionospheric information result in requirements for

NPOESS. For example, current support provided to HF communication systems is seen as adequate and the need for this support may be reduced in the use of the Automated Link Establishment (ALE) technology becomes widespread. The use of dual-frequency altimeters, as opposed to the single-frequency instruments currently in use, should eliminate the need for ionospheric corrections for this type of observation system in the NPOESS era. Also, many (but not all) types of ionospheric support to radars are best performed through the use of local, ground-based measurements. Thus, the DoD systems which actually drive requirements for NPOESS are satellite communication and navigation systems (primarily through the need for predictions of ionospheric scintillation), National Programs, and high-latitude radars.

The group also reviewed DoC requirements related to the ionosphere, including support for communications, navigation, and electrical power distribution systems. The working group found that the DoC requirements are more difficult to trace back to an end user. This is primarily due to the DoC charter for providing space environment support through the SEC which allows the agency to provide only very limited support tailored to specific end user needs. Figure 4 illustrates the current CONOPS developed by the NOAA SEC to provide “Space Weather” support to users. This CONOPS is in marked contrast to the DoD role in “Space Weather” in which nearly all products are tailored to specific end users. The DoC charter provides for measurements which allow the SEC to maintain a general level of “global situational awareness” and to provide their customers with a specification of the current level of ionospheric activity. NPOESS will support this need primarily through high-latitude (auroral zone) measurements and solar data. More detailed ionospheric information; for example, electron density profiles (EDPs),

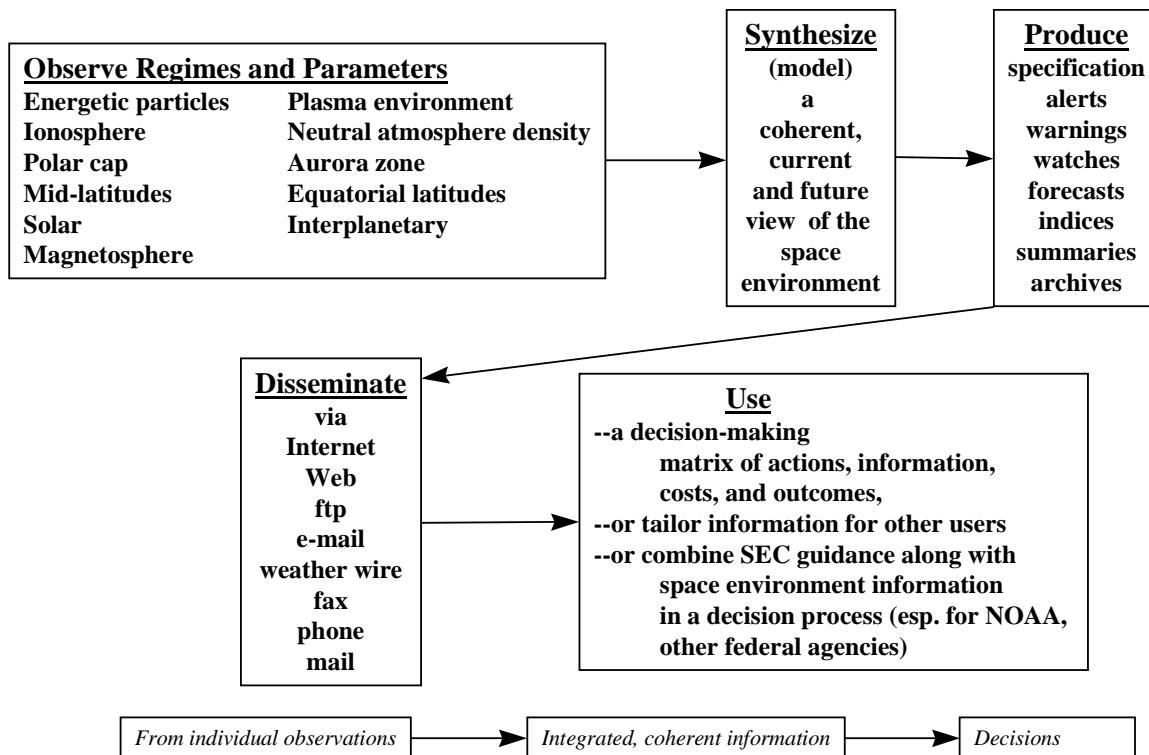


Figure 4. NOAA SEC Space Weather CONOPS

may be useful to the DoC under some circumstances but the DoC charter does not result in a requirement for NPOESS to make these measurements. This is generally true for all of the space environmental measurements which might be required by DoD assets - they are useful to the DoC but not required by them to do their job.

Apart from the DoC requirement for data leading to global situational awareness, user needs for ionospheric specification fall into two areas; 1) corrections related to changes in electromagnetic wave propagation induced by the ionosphere and 2) knowledge of when systems will be or are being impacted by ionospheric disturbances; that is, scintillation and auroral clutter. In general NPOESS can contribute to the first of these areas by providing EDP measurements on a global basis. Measurements of electron and ion temperatures are of some importance as well since such measurements can be

related to EDP characterization; for example, topside scale heights. It is anticipated that the EDP measurements will be ingested into an assimilative model together with other ground and space-based data to produce an accurate global ionospheric specification. Such a system could meet the needs of National Programs, as well as provide single-frequency GPS users with accurate estimates of positional errors. Due to coverage and refresh considerations, the 3-satellite NPOESS system would not provide enough data to fully meet these needs without being augmented by ancillary data. The NPOESS data by itself does, however, provide a significant amount of the data necessary to meet end-user requirements. The group also considered an alternate CONOPS utilizing a first-principles model driven by measurements other than EDPs. However this approach was considered too immature, at present, to drive NPOESS requirements. Additional research is required to assess the utility of such an approach.

In the case of systems that are impacted by ionospheric disturbances, NPOESS makes significant contributions at both high and low latitudes. At high latitudes, measurements of the auroral boundary are of particular importance since this EDR determines the latitude above which scintillation activity is expected; that is, in the auroral zone and the polar caps. Auroral imagery over radar sites equipped with tactical terminals can allow rapid evaluation of the existence of auroral clutter; that is, regions of intense auroral precipitation, within the radar field of view. At low latitudes, measurements of electric fields and EDPs will facilitate the forecast of equatorial scintillation. Relative to low-latitude scintillation forecast, the neutral wind is known to be a contributing factor in the generation of scintillation structures - the group therefore recommended that this additional space EDR be offered for consideration. (Editorial

Comment: The neutral wind EDR was also recommended by the satellite drag - atmospheric density working group). High-latitude electric field observations are also useful for predicting the motions of scintillating plasma patches. Measurements of in-situ plasma fluctuations can be used to quantitatively predict scintillation levels at both high and low latitudes. However, direct observations of ionospheric scintillation from NPOESS are seen as less useful, operationally, due to the availability of data from various communication and navigation satellites and coverage gaps associated with the NPOESS orbit at low latitudes. An equatorial satellite; for example, the AFRL Communication and Navigation Outage Forecasting System (C/NOFS) would provide a better product for low-latitude scintillation specification and prediction but it is uncertain whether such a satellite will exist in the NPOESS era. Even with an operational C/NOFS in place the NPOESS data will still have a significant “value-added” contribution due to its latitudinal coverage particularly in the post-sunset local time where ionospheric scintillation is strongest.

4.1.2. *CONOPS for Ionospheric Effects and Scintillation*

The working group studied existing and future CONOPS for space environmental support in each of the mission areas previously discussed. We present here a single example of a future CONOPS that will provide support to a user mission, in this case, low-latitude satellite communication (SATCOM) as shown in Figure 5. Data in this CONOPS is obtained from a variety of sources, including the NPOESS. These data are used within Data Centrals as input to assimilative models of the ionosphere and in first-principles plasma physics models predicting the occurrence of scintillation. Alternately, a

subset of these data can be used in empirical models for specifying scintillation. The Data Centrals support users in the field by maximizing assured SATCOM connectivity.

4.1.3. Impacts to the NPOESS space EDRs

The NPOESS EDRs were evaluated and prioritized according to their perceived utility as well as the amount of research required for their implementation. Table 2 provides the final prioritization for the space EDRs as recommended by the Ionospheric Effects and Scintillation working group. EDRs having demonstrable value in meeting a valid operational need were ranked high. All of the DoC requirements leading to global situational awareness (auroral boundary, electric field, auroral energy deposition, and solar extreme ultra-violet [EUV]) fall into this category, as do the DoD requirements for auroral boundary and auroral imagery. EDRs for which there was a clear need but which

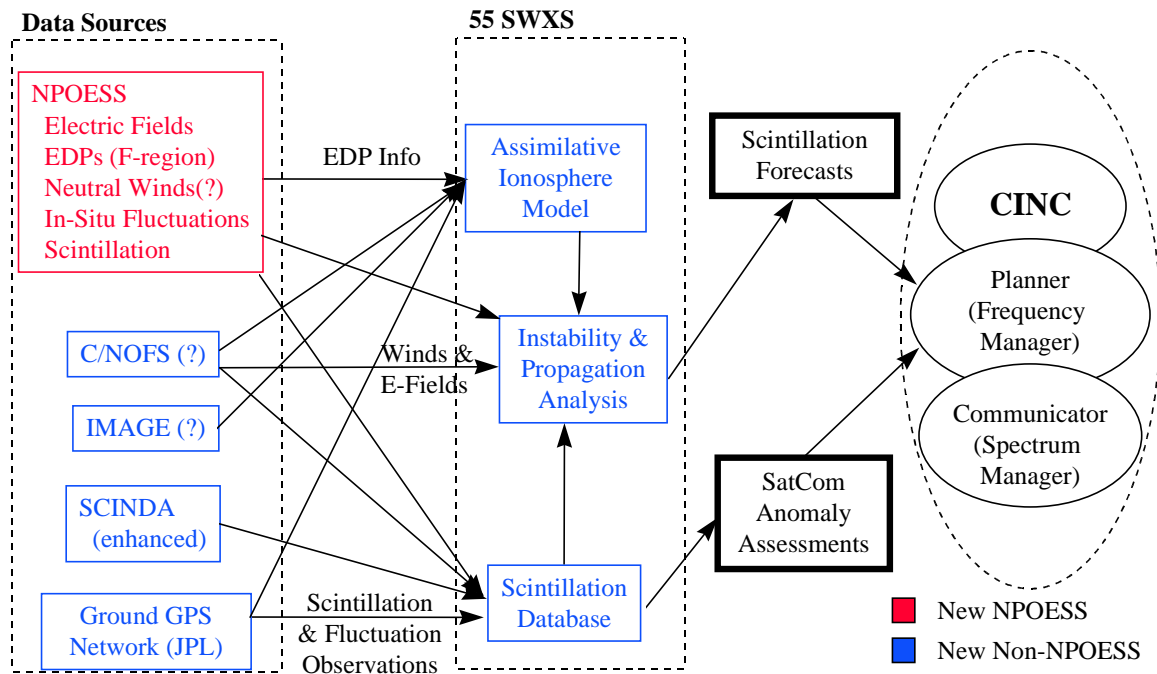


Figure 5. Future CONOPS for Satellite Communications (Low Latitude)

were associated with a CONOPS that requires further research prior to implementation were ranked lower. The EDPs and the various scintillation-related EDRs (but not the scintillation EDR itself, as discussed above) are examples of important data products for which additional research is required. However, the EDPs received a relatively high ranking because of its applicability to all of the DoD user needs reviewed in this study. EDRs which might be relevant to the operational area of interest, but which were not considered to be part of the most likely CONOPS for meeting user needs were ranked the lowest. The new neutral winds EDR was not ranked, because the working group was uncertain whether the creation of a new EDR was acceptable. If it was ranked, this EDR would appear below in-situ plasma fluctuations. Also not ranked were two EDRs considered to be of no use for ionospheric support, and three EDRs which the group recommended be deleted or merged with other similar EDRs. The deletion of the UV airglow EDR was recommended because this measurement represents a particular sensor solution for determining the EDP and the neutral density profile (NDP) and, as such, is not appropriate at the IORD level. The in-situ drift velocity and plasma density EDRs were considered redundant and were merged with the electric field, EDPs, and in-situ plasma fluctuations EDRs.

Ranking	EDR	Ranking	EDR
1	Auroral Boundary	10	Scintillation
2	Electric Field	11	Precipitationing Auroral Particles
3	Auroral Energy Deposition	12	Neutral Density Profiles
4	Electron Density Profiles	New	Neutral Winds
5	Solar EUV	N/R	Geomagnetic Field
6	Auroral Imagery	N/R	Cosmic Rays
7	In-situ Fluctuations	Deleted	UV Airglow
8	Radiation Belt Particles	Merged	In-situ Drift Velocity
9	Electron / Ion Temperatures	Merged	In-situ Plasma Density

Table 2. Ionospheric Working Group EDR Prioritization

Most of the changes recommended by the Ionospheric Effects working group for the NPOESS space EDR attributes are minor corrections which either bring an attribute into alignment with an end-user need or correct some an obvious error in the parameter. An example of the first kind of correction is the change in auroral boundary threshold accuracy from 50 to 100 km - the working group felt that the latter value was a more realistic estimate of the maximum useful resolution for radar clutter assessments. An example of the second kind of correction is the change in in-situ plasma fluctuations in-track resolution objective from 5 m to 100 km - the 5-m value being the instrument sample rate that might be used to determine the average fluctuation levels and the associated spectral characteristics. The revised value for the in-track resolution is more commensurate with the specification of the spectral index within a reasonable horizontal cell size.

Apart from the one new EDR (neutral winds) and the three deleted or merged EDRs already discussed, the most significant changes were made to the EDPs and auroral imagery EDRs. The EDP EDR had several additions made to clarify the traceability to

various operational users of this data. This occurred because different aspects of the profiles are important for different applications and in different geophysical regions. However, it is not clear that this level of information needs to be preserved at the IORD level. The specification of a measurement range for auroral imagery was made more general to allow the contractor to investigate various sensor options instead of being tied to a solution in the far ultraviolet. However, it should be noted that the objective wavelength range previously specified was in error in any case and should have been the same as the threshold if a far ultraviolet (UV) sensor is in fact required. Finally, the UV airglow EDR was provided with a new set of measurement range values which are more representative of the naturally occurring airglow levels. These changes should be made if the recommendation to remove this EDR is rejected.

4.2 Orbital Drag - Atmospheric Density Working Group

The Orbit Drag - Atmospheric Density working group met during the Summer of 1997, with subsequent telephone calls among select members to arrive at the Task 2 results for this mission area. The process that the team followed was; 1) understand and validate end user requirements, 2) discuss the state of the science today and future expectations for neutral density modeling techniques, 3) document current, near-term, and future CONOPS, 4) determine NPOESS' role in future CONOPS, 5) define EDRs that will meet future user requirements, and 6) justify the EDRs, the parameters, and the parameter values.

4.2.1. *User Needs Assessment*

The user requirement for orbital drag is actually a requirement for orbital ephemeris accuracy. The users we interviewed were; Cheyenne Mountain Space Control

Center (including national systems support), National Reconnaissance Office, select satellite owners/operators, NASA Marshall Space Flight Center, and Naval Space Command. Since there are numerous ways to obtain increased orbital ephemeris accuracy; for example, use of GPS, the team defined the users / user needs that require increased accuracy and apply orbital drag models to characterize and predict orbital propagation. There are a large number of users requiring the General Perturbations (GP) orbital ephemeris determination and prediction. However, our study focused on the select users of the more accurate Special Perturbations (SP) ephemeris determination and prediction. The SP solution uses drag modeling to obtain the final solutions.

Drag prediction is required in three areas; 1) maintaining a catalog of the ephemerides of space objects, 2) collision avoidance, and 3) reentry predictions. Quantitative studies that relate specific orbital prediction requirements to neutral density accuracy requirements are few, at best. We were able to identify only one such study. The basic problem is twofold. Either specific orbital prediction requirements have not been documented or, when requirements exist, the connection between the orbital prediction requirement and neutral density accuracy has not been quantified. In the area of ephemeride prediction, we were able to identify a requirement only for DMSP. Orbital prediction accuracies are implicit in the standoff requirements for debris in Space Shuttle and Space Station operations. Yet the density accuracy requirements corresponding to these standoff distances have not been quantified. Similarly, requirements for reentry prediction exist, but the sensitivity of neutral density errors compared to other uncertainties has not yet been quantified. However, the working group believed that stressing requirements will emerge from the requirement to maintain a large catalog of

space objects, address collision avoidance concerns, and provide more accurate reentry predictions.

The objective requirements for density accuracy derive from a single quantitative study. This study addressed the growth in the orbit prediction error with time for fixed fractional errors in density at different altitudes. The team noted that, in this study, the density was held constant throughout the simulations. This means that the accuracy requirement that flows from this study should be interpreted as a requirement for the accuracy of orbit-averaged and time-averaged density. This can be very different from the accuracy stated in terms of point values. The values of model accuracy that are used to state model capabilities are usually stated in terms of point values. A study has been performed by Frank Marcos at AFRL to evaluate model accuracy in terms of orbit- and time-averaged values. Current neutral density models provide a ~15% accuracy, point-to-point. For the data studied by Marcos, the results show that averaged standard deviations are 2 - 3.5% less than the 15% point value accuracy. The orbit-averaged accuracy requirements specified provided by AFSPC for the threshold neutral density is 10%. Therefore, today's systems and models are not meeting validated neutral density accuracy requirements.

The team considered a variety of ideas to improve density specification and prediction in support of orbit determination. One such method is use of a neural network (ref: "Some Prospects for Artificial Intelligence Techniques in Solar-Terrestrial Predictions, D. J. Gorney, H. C. Koons, and R. L. Walterscheid, The Aerospace Corporation). Another we considered is direct ingest of solar EUV data into operational density models. Although these methods have merit, the team decided that assimilative

models and first-principles (physic-based) models are the most feasible to implement with the greatest promise for improving orbital prediction accuracy via density improvements. Examples of the utilization of these assimilative and first-principles models are shown in the CONOPS to follow.

We identified neutral winds as an item for future study. The drag force is related to the velocity of the satellite (or debris) relative to the wind velocity. At high latitudes during disturbed conditions winds can be a 20% effect relative to no-wind conditions. Upper atmosphere winds can be measured from space using passive optical instruments; for example, a Fabry-Perot Interferometer, that detect Doppler shifts in airglow emissions. These instruments are not part of the baseline payload and represent an increase with respect to cost and demands on satellite resources. We decided not to include a requirement for winds since the utility of wind measurements is uncertain, pending further study.

The ability to accurately predict neutral density in stressing solar and geomagnetic conditions is limited by the ability to accurately predict solar and geomagnetic activity. Presently, the skill scores for predicting solar activity is marginal and forecasting geomagnetic activity is slight (less than marginal). We believe that efforts to improve drag prediction should be coupled with efforts to better characterize and predict solar and geomagnetic activity.

In order to investigate and validate end-user requirements for orbital drag and neutral density accuracy, two members of the team traveled to Colorado Springs to meet with the space surveillance/space control community. During this trip, we met with a variety of users, including Cheyenne Mountain Operations Center (CMOC) Space

Control Center (SCC) operators (including those that explicitly support national systems), AFSPC Space Warfare Center (SWC) personnel (whose job it is to provide astrodynamic support to CMOC), MITRE, and various others. The overall question we were trying to answer was; “Given that the requirement on the books has not been met, is it still a valid requirement?” (reference 18 Apr 88 letter from ADM Breast, US Space Command/J3 to AFSPACECOM/DO/XP, “Requirements for Improved Density Models”) The astrodynamic community gave us qualitative reasons for the need to improve density accuracy. We then contacted Major Christianson, HQ US Space Command/J33Y, asking for a HQ position on this requirement. He verified, via a phone conversation on 4 June 1997, that the requirements as stated in the reference letter were still valid although they should be treated as objective requirements. This is consistent with what we heard from AFSPC/SWC. We then asked Major Christianson who could define the threshold requirements for us, and he stated that the SWC representative on our team (Mark Storz) could do that for us. Mark Storz provided his input on the threshold requirements during our team meeting in Boulder on 5 June 1997. These values (threshold and objective) are listed for the accuracy values in the Neutral Density Profile EDR.

4.2.2. *CONOPS for Atmospheric Density Specification and Prediction*

With the aforementioned information as background, the team arrived at the following CONOPS:

- Current - ground-based sensors providing proxy values to empirical density models
- Near-term - use of space surveillance tracking data to enhance density prediction

- Future (threshold) - Assimilative process relying on space-based sensing to enhance empirical models
- Future (objective) - Assimilative process and first-principles models relying

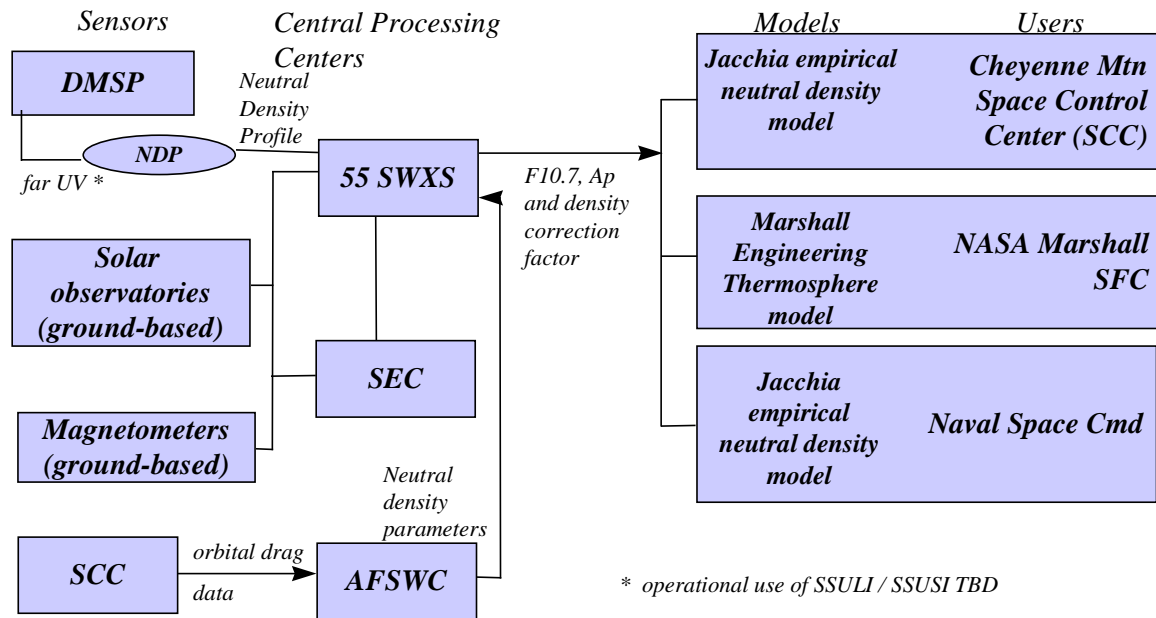


Figure 6. Near-term CONOPS for Atmospheric Drag Prediction

on space-based sensing to enhance empirical models.

The team noted in the near-term CONOPS of Figure 6 that the validation and operational utility using remote sensing of the atmosphere in the far UV to derive the neutral density profile remain an issue. This is important in that this type of data from, for example, SSUSI and SSULI will determine the feasibility of our future threshold CONOPS. However, work is in progress to validate the SSUSI and SSULI technique and associated algorithms. There are ideas as to how this information may be used operationally but these ideas have not yet been validated. The ARGOS experiment, due to fly in late 1998 will fly the LORAAS instrument - copy of SSULI - and the LORASS

data will be used to validate the UV technique. The Naval Research Laboratory (NRL) plans to use the LORAAS data to test the SSULI algorithms. In turn, the SWXS will use the output of the SSULI algorithms in the Navy's SP space object catalog (using MSIS as

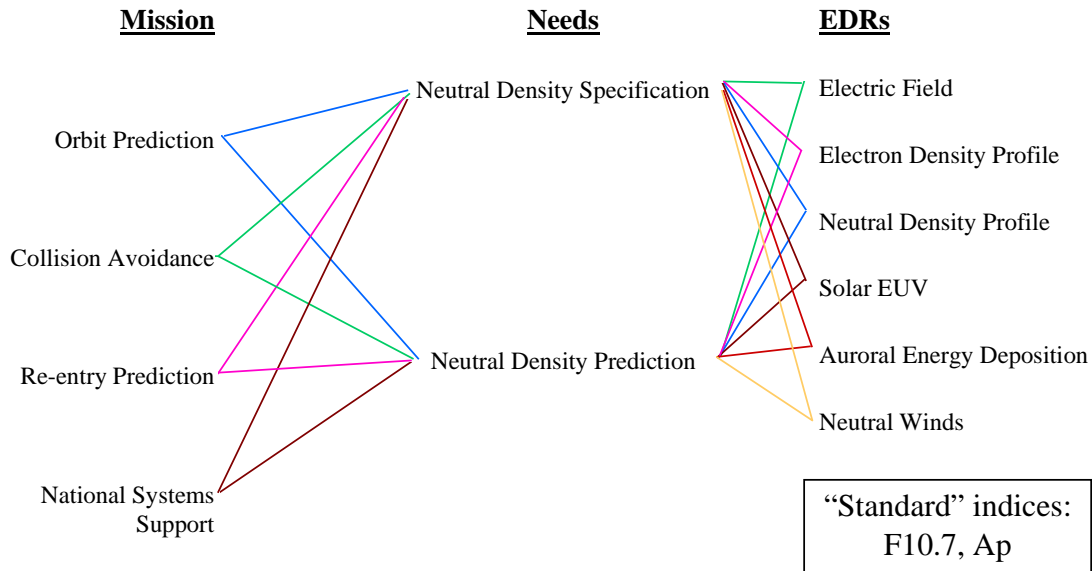


Figure 7. Mapping from the Mission Area to Needs & User Needs to EDR

the density model) in order to assess the effects of UV data on orbit-determination accuracy. Preliminary results of this experiment may be ready mid 1999 assuming ARGOS is launched according to schedule. DMSP S16-20 will fly SSUSI and SSULI in the post CY2000 time frame.

4.2.3 Impacts to the NPOESS Space EDRs

Figure 7 shows the mapping from the mission requirements for ephemeris determination and prediction to the user needs and then from the user needs to the NPOESS space EDRs. Overall, the working group determined that changes were needed to the IORD-I requirements for the following EDRs; 1) Auroral Energy Deposition, 2) Electron Density Profile 3) Neutral Density Profile and 4) Solar EUV Flux. We also verified the use of Electric Field as an objective requirement to support our future

CONOPS, although no changes were required to this EDR. The group recommends deletion of the In-situ Drift EDR since this EDR assumes a specific implementation to obtain electric field, and is therefore redundant with the Electric Field EDR. We also recommend the addition of a Neutral Winds EDR as an objective requirement to support our future CONOPS. The recommended changes to the EDRs and detailed justification can be found in the briefing “Task 2: EDR Assessment and Validation / Orbital Drag - Atmospheric Density Working Group” provided in the appendix. The detailed justification is documented in the “notes pages” of the briefing. A prioritization of the

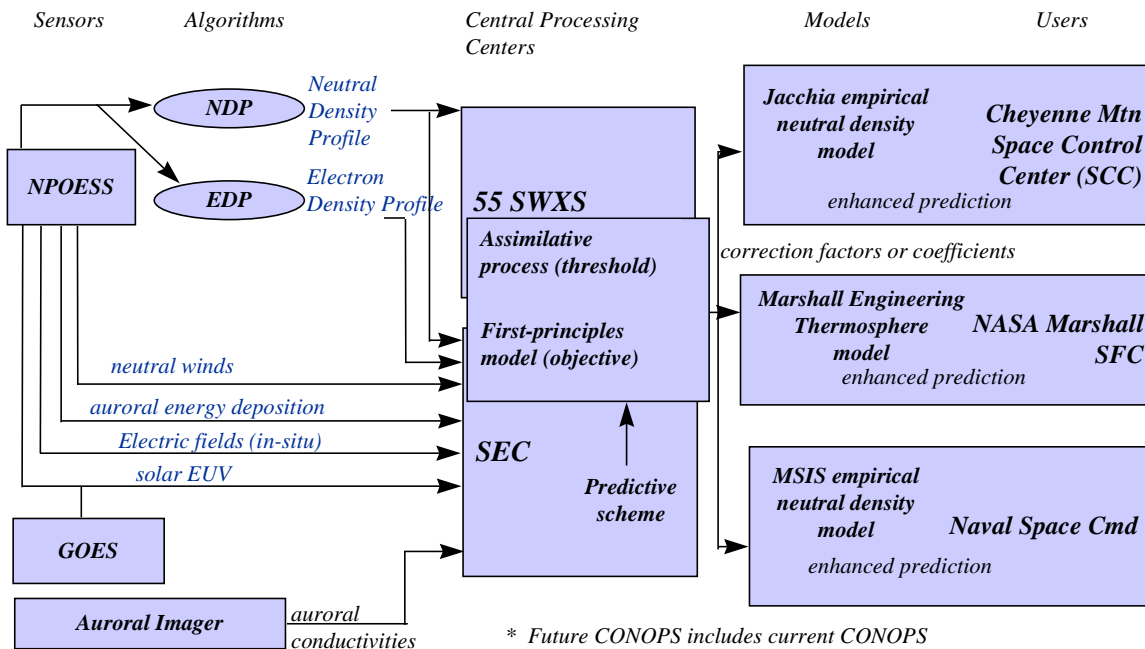


Figure 8. Future CONOPS for Atmospheric Drag Prediction

EDRs with respect to this mission area can also be found in this briefing.

It is important to note that the majority of the recommended EDR changes from this team affect objective requirements only since their use is predicated on first-principles models and the operational use of first-principles models for orbital drag is a subject of research (see Figure 8 for the future CONOPS). By and large, the requirements

for EDRs related to first principles models were based on modeling experience and the best judgment of first-principles modelers. Therefore, the only EDR the team recommends changing that affects threshold requirements is the Neutral Density Profile. The team recognizes that it may be challenging to meet the threshold accuracy requirements for this EDR with the current technology instruments; that is, SSULI/SSUSI. These instruments measure remotely altitudes up to around 350 km. The remainder of the profile, up to 750 km, must be extrapolated from the remotely-sensed data. The estimated accuracy obtainable at these extrapolated altitudes is 20%. By providing an in-situ measurement of total density (at NPOESS altitude), an interpolation scheme could be used to provide better accuracy. The working group took care to trace back the threshold accuracy requirement for this EDR to end-user validated requirements. Therefore, in spite of the added complexity the team continues to recommend this change.

4.3 Satellite Design and Anomaly Resolution Working Group

The Satellite Design and Anomaly Resolution working group was primarily concerned with the safe and efficient operations of satellites and other space assets, including manned spaceflight. As with the other two working groups, this group was asked to document existing CONOPS, identify future CONOPS, and to assess and prioritize the NPOESS EDRs within the context of the assigned mission areas. The mission areas assigned to this group were Satellite Operations, Manned Spaceflight, High-Altitude Aircraft, and Satellite Design. The group identified the key space environmental effects that impact user performance and the current and future space environmental products needed by the user. The group did a mapping from these space environmental effects to the NPOESS space EDRs. In this regard, the group was cognizant of existing or likely

alternative data sources to the NPOESS. Finally, the group assessed the existing NPOESS EDRs and optimized these EDRs to provide cost-effective solutions for the IPO.

4.3.1 User Needs Assessment

A key output from Task 1 was a user-needs assessment in the assigned mission areas. This assessment found that in general; 1) satellite operators require real-time to post-event space environmental data for spacecraft anomaly assessments, 2) space-radiation hazard prediction and radiation total-dose assessments are required for manned spaceflight and for high-altitude aircraft operations, and 3) representative long-term data sets are needed for satellite designers. A number of the working group members provide day-to-day satellite anomaly assessments and data products to satellite operations and designers. These member were acutely aware of user needs and could relate these needs to specific effects of the space environment. The key space environmental factors affecting mission performance were identified and related to current and future product needs. The mapping from the mission areas to the required products is shown in Figure 9.

4.3.2 Space Environmental Effects

The following are descriptions of the space environmental effects that pertain to this working group:

Surface charging - surface charge build-up of exposed dielectric materials due to energetic, that is 50 eV to 150 keV, electrons. Differential charging of surfaces can lead to significant voltage differences on adjacent surfaces. The electrical discharging of these surfaces can induce large current spikes within the spacecraft thereby

degrading mission effectiveness. The local plasma density or the presence of photoelectrons (in sunlit) can affect the differential charging rates.

Deep-dielectric charging - voltage build-up by charge particles, mostly electrons, that have sufficient energy to penetrate the surface of exposed dielectrics and be “trapped” within the material. The energies for the particle flux responsible for deep-dielectric charging range from 100’s of eV to greater than 1 MeV. As in the case of surface charging, it is the discharging of the material that causes large current spikes within the spacecraft. The ejected material from the discharge channel can also momentarily increase the local neutral density and be a source of contamination for the spacecraft. The discharge is statistical and can occur minutes or hours or even days after exposure to the charged particle flux. Thus it is often difficult to associate the discharge, and indeed a satellite anomaly, to a past particle flux that caused the charge build-up.

Single-event upsets - system anomalies caused by high energy charged particles have

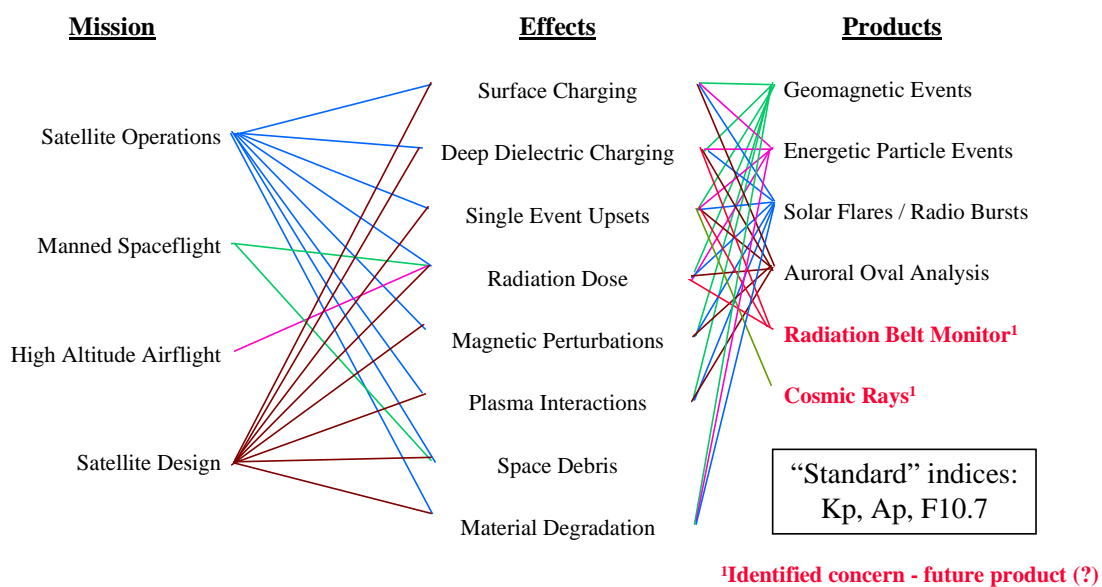


Figure 9. Mapping Mission Area to Space Environmental Products

sufficient energy to penetrate deep into a spacecraft and can affect the operations of sensitive electronics. The major affect is from greater than 50 MeV protons (and other heavy ions) from the inner radiation belts or from cosmic rays. Satellite anomalies resulting from single-event upsets are, quite often, transient bit flips or changes of state that can degrade system performance. However, other similar upsets; that is, single-event latch-ups or single-event burnouts, can cause permanent damage to electronic components and the spacecraft.

Radiation dose - Total radiation dose is the integrated flux of ionizing radiation into sensitive electronic components. The energy range for the charged particle flux is from hundred's of keV (electrons) to hundreds of MeV (protons). Particles of this energy can affect the material properties of semiconductors leading to degraded system performance and loss of efficiency within solar cells. The region of greatest concern is the inner (high-energy proton) radiation belts although the outer belts (lower energy protons and electrons) as well as solar protons in interplanetary space can also degrade satellite performance.

Magnetic perturbations - sudden variations in the earth's local geomagnetic field can adversely affect spacecraft attitude control systems (ACS) that use magnetic torquing devices. The magnetic variations due to geomagnetic storm effects are often very small relative to the background field but, at rare times, can be sufficient to cause erratic behavior in the ACS.

High-voltage / plasma interactions - operations requiring high-voltage; that is, 100's of volts, can be degraded due to background thermal plasma effects. A typical application might be a large solar array on a satellite in Low Earth Orbit (LEO).

Depending on the polarity and size of the array there could be significant potentials at the ends of the array. Large positive potentials relative to the background can result in electrical arcing and spallation of exposed material. Large negative potentials, on the other hand, can cause leakage currents and degraded power efficiency.

Space debris - space debris or micro-meteorites can impact a spacecraft and cause damage due the high-momentum collision. Space Surveillance networks routinely monitor space debris down to several centimeters. Space debris can either be manmade or be of natural origin. NASA and the DoD maintain the space object catalog. Considerations of space debris are beyond the scope of this report.

Material degradation - atomic oxygen (OI) is a very reactive element and a dominant atmospheric constituent between about 200 to 400 km in altitude. Oxygen erosion can degrade mechanical, thermal and optical properties of exposed surface material in LEO. The total fluence of OI is the parameter of interest for this space environmental effect.

4.3.3 *User Products*

The Data Centrals provide the users with a variety of real-time products from which the space environmental affects can be assessed (maybe). The list provided in the right-hand column of Figure 9 is a fairly generic, but applicable, description of these products. Current products are specifications of the general level of geomagnetic activity and of solar activity. Monitoring of the sun is useful, but inaccurate, as a predictive index of geomagnetic activity. A key data product currently unavailable is an assessment of the Van Allen radiation belts. While NPOESS may not be in the ideal orbit to monitor the radiation belts the satellite will provide a telltale indicator of the general strength of the

belts. The overwhelming advice from the working group was that space environmental data must be continually collected and archived so that in the event of a satellite anomaly or for spacecraft designers sufficient information exists to support the non real-time users. The products used for satellite design and anomaly resolution are used in a variety of CONOPS which this group concentrated into the main mission areas.

4.3.4 *CONOPS for Anomaly Resolution & Satellite Design*

The group studied existing as well as hypothetical CONOPS in terms of current, near-term (revised), and future user needs. For the purposes of the working group, the future is identified as the NPOESS era. The key features describing the current, revised, and future CONOPS for the three mission areas are summarized below. Each mission area is covered in turn.

- Satellite Anomaly Resolution
 - Current - Standard products and tailored support
 - Revised - Real-time data to users; expert system
 - Future - In-situ health & status; radiation belt support
- Manned Spaceflight & Aircraft Operations
 - Current - Direct support to NASA / DoD
 - Revised - No change
 - Future - Low altitude radiation support
- Satellite Design
 - Current - Limited overarching support
 - Revised - Centralized support network
 - Future - No further change

For satellite anomaly assessments, the space Data Centrals, such as the 55SWXS or the NOAA SEC, rely on a variety on input data to provide standard products or tailored support to users. A general description of this CONOPS is illustrated in Figure 10.

While this represents the future CONOPS, many elements of the current system are envisioned to remain intact. In the major categories, labeled solar observations, space particles, and geomagnetic activity, it is probable that these data will exist in any future architecture. Overall, the working group felt that the current status of data availability to the Data Centrals was good but sparse. The future enhancements over the current

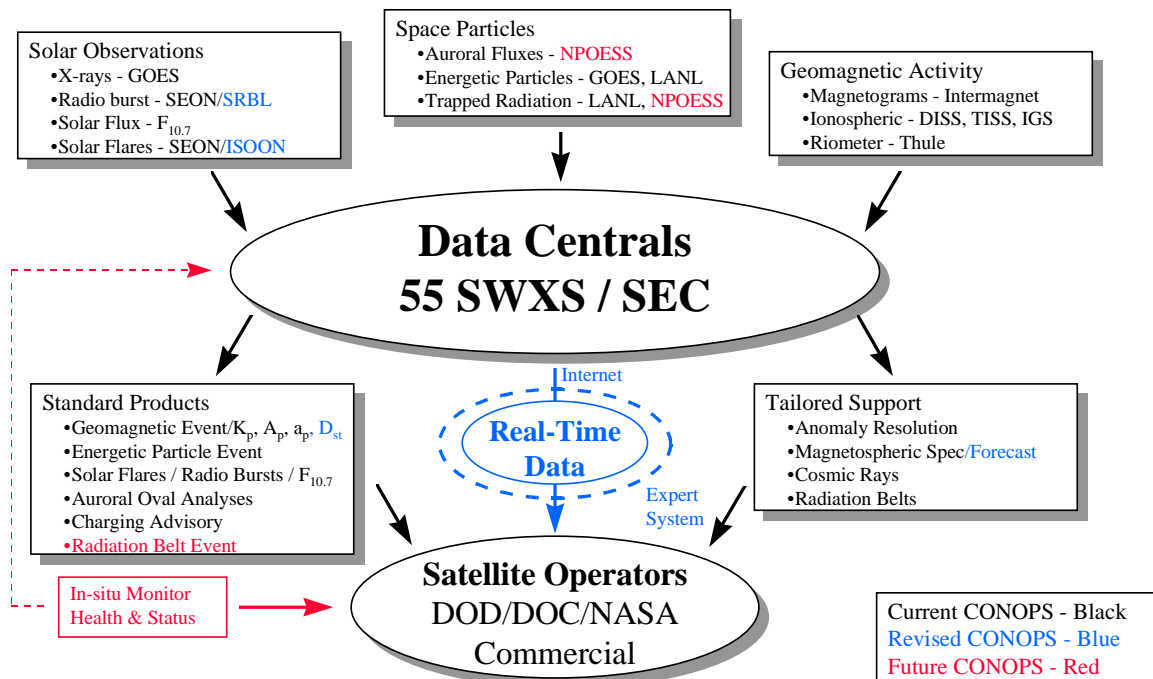


Figure 10. Future CONOPS for Satellite Anomaly Resolution

architecture will be for an increased number of in-situ monitors on a variety of space platforms to which, hopefully, the Data Centrals have access. The increased role of NPOESS in the future, over that of DMSP, will be to provide an improved specification

of the high-energy, charged-particle environment within the Van Allen radiation belts and from solar (and galactic) cosmic rays.

Space environmental support to manned spaceflight and for high-altitude aircraft has a narrowly focused role, now and in the future. Current products use the space environmental data to specify and predict regions of potentially high-radiation flux; for example, the enlarged auroral zones during periods of increased geomagnetic activity. The CONOPS supporting these mission needs is shown in Figure 11. The increased role for NPOESS will be to measure the higher-energy, charged-particle fluxes precipitating to lower altitudes thereby affecting manned spaceflight (space station) and high-altitude aircraft.

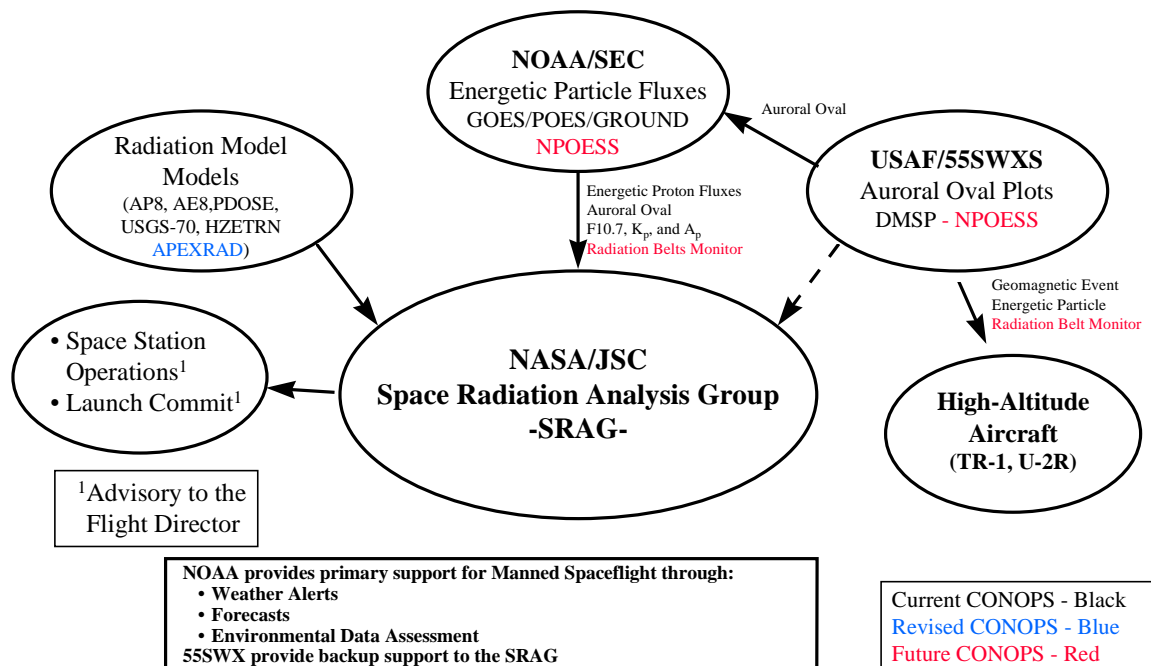


Figure 11. Future CONOPS for Satellite Anomaly Resolution

For those CONOPS having to do with satellite design, the working group recognized that there currently exists a wealth of data but that the area suffers from a lack

of a centralizing function (see briefing charts in the appendix). This centralized function is not the mission of the current Data Centrals and it is not clear if it even ought to be. To this end, initiatives such as the NASA Space Environment and Effects (SEE) program are good and should continue to evolve as a centralized data repository for “cause and effect” of space environmental interactions.

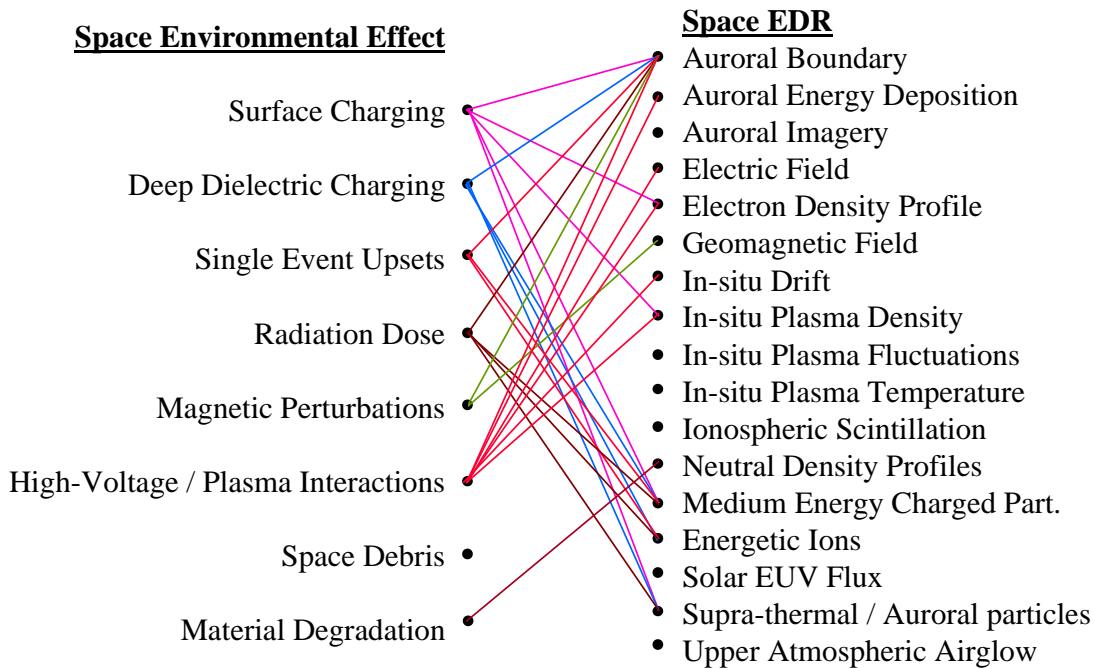


Figure 12. Mapping from the Space Environmental Effect to the NPOESS space EDRs

4.3.5 Impacts to the NPOESS Space EDRs

The mapping of space environmental effects to the list of NPOESS EDRs was assessed by the Satellite Design and Anomaly Resolution working group and is provided in Figure 12. This mapping is quite general and, at this level, indicates that the “effects” can be mapped into a fair number of EDRs. What is not so apparent is the relative importance of each EDRs to the overall mission areas. In order to assess the impact of each EDR the working group considered the full set of EDRs within the context of the

existing-to-future CONOPS. The results of this consideration are provided in Figure 13 as a prioritized list (highest -to- lowest) of space EDRs. The categories indicate whether the EDR is a Class I (operationally viable) or Class II (demonstrated viability) data product and the importance of that EDR (High, medium, low) to the mission area. The working group felt that many of the existing EDR specifications served these mission areas well and, with the recognition that the needs of the other working groups are complementary, deferred to these other working groups for revised EDR specifications in a number of areas. The working group did assess, however, the full set of space EDRs.

SES EDRs	Category	WG Comments
Supra-thermal/Auroral Part.	I/High	Determine charging environment
Auroral Boundary	I/High	Determine charging environment
Medium Energy Charged Part.	I/Moderate	Assess radiation belt / polar radiat
Auroral Energy Deposition	I/Moderate	Assess geomagnetic “stress” levels
Electron Density Profile	I/Moderate	Assess charging environment
Electric Field	II/Moderate	Assess geomagnetic “stress” levels
Geomagnetic Field	II/Low	Assess magnetic perturbations
Energetic Ions	II/Low	Assess radiation environment, polar/SAA
Neutral Density Profiles	II/Low	Atomic O specification
Auroral Imagery	n/a	Redundant - see E-field Redundant - see electron density
In-situ Drift	n/a	
In-situ Plasma Density	n/a	
In-situ Plasma Fluctuations	n/a	
In-situ Plasma Temperature	n/a	
Ionospheric Scintillation	n/a	
Solar EUV Flux	n/a	
Upper Atmospheric Airglow	n/a	

Figure 13. NPOESS Space EDRs Maturity and Relevancy.

The working group offers the following:

Supra-thermal / Auroral Particles - The EDR is fundamental to a number of CONOPS for manned spaceflight and satellite anomaly resolution. Specifically, the data are used to determine the auroral boundary (CONOPS defined) and the auroral energy deposition (tailored support).

Auroral Boundary - This is a derived EDR either from particle precipitation (current) or auroral imagery (no longer used). This EDR has high relevancy for manned spaceflight (CONOPS defined), particularly shuttle operations, in assessing the radiation environment; that is, the general level of radiation flux. Total dose forecasts are derived primarily from climatological models, for example AE8 and AP8. The low-latitude position of the auroral boundary is also useful for assessing the overall geomagnetic disturbance level.

Medium Energy Charged Particles - This energy range is particularly useful in assessing the Van Allen radiation belts and solar-proton precipitation along the open magnetic field lines within the polar cap. Solar-proton precipitation at high latitudes is of concern to aircraft and spacecraft operations. The working group recognizes, however, that the key data inputs used to monitor energetic particle events are from the GOES satellites. This EDR on NPOESS will also provide a telltale indication of particle characteristics within the radiation belts from trapped particles that are magnetically mirrored below the NPOESS altitude. It is noted however that a more optimum location from which to make measurements of the radiation belts is a satellite in a GEO-transfer orbit or even a Molniya orbit. A dawn-dusk orbit is the optimum local-time orientation. Total dose measurements are also useful to assess spacecraft power system degradation.

Auroral Energy Deposition - Provides information as to the general level of geomagnetic activity. The energy deposition is typically derived from a measure of the “along-the-track” auroral energy flux and related to global auroral particle energy maps. This

EDR can also be derived from the intensity of auroral emissions at UV wavelengths.

Used for tailored product support.

Electron Density Profile - Used to deduce the local electron density for a satellite in LEO.

Related to spacecraft charging at auroral latitudes and in darkness. Used for tailored product support.

Electric Field - The general level of geomagnetic “stress” can be inferred from the strength and extent of the convective electric fields at high latitudes. The polar-cap potential is derived by integrating the electric field across the polar cap. Used for tailored product support. The polar-cap potential is used in the Magnetospheric Specification Model (MSM).

Geomagnetic Field - This EDR provides information for satellite anomaly resolution.

Perturbations in the geomagnetic field, primarily at auroral latitudes, can adversely affect satellite attitude control systems (magnetic torque wheel). It is uncertain as to how this will be used for tailored product support.

Energetic Ions - Energetic ions (>10 MeV) from the Van Allen radiation belts (inner belt) and from solar and galactic cosmic rays, including solar protons. A satellite in GEO is the preferred platform from which to monitor cosmic rays. Rather than specifying the composition and energy range for the measured particles, it is often useful to consider the effect on space electronics as the Linear Energy Transfer (LET). Uncertain as to how this will be used for tailored product support - existing measurements from GOES provide an adequate level of service for solar proton flux and cosmic rays.

Neutral Density Profile - Useful for determining the cumulative effect of atomic oxygen erosion on spacecraft surfaces and materials. The key parameter is the fluence onto an optical or insulating surface which is likely to have a degrading effect or a catastrophic impact due to the total fluence of OI. Useful as a secondary effect for tailored product support.

The Satellite Design and Anomaly Resolution working group was tasked to make specific recommendations for revisions to the IORD-I set of space EDRs. These recommended revisions are as follows;

EDR 4.1.6.7.15 - Supra-thermal to Auroral Energy Particles

- Increase from 30 keV to 50 keV (objective of 100 keV), the high energy cut-off for the auroral protons and electrons. The justification is based on recent results on the charging of the DMSP satellite as reported by Anderson et al., [1996].

EDR 4.1.6.7.13 - Radiation Belt and Low Energy Solar Particles

- Increase the low energy threshold from 30 keV to 50 keV per EDR 4.1.6.7.15. This change should also simplify the overall sensor design. It is further suggested that the EDR be renamed from “Radiation Belt & Low Energy Solar Particles” to “Medium Energy Charged Particles”,
- Separately identify the energy ranges for protons and electrons and reduce the high-energy electron cutoff from 10 MeV to 1 MeV in EDR 4.1.6.7.13. The number of electrons with energies greater than 1 MeV is small. Objective level for electron is 10 MeV,

- Change the particle flux ranges from $10^6 - 10^{11}/\text{m}^2\text{-s-ster}$ to $10^6 - 5(20)\times 10^{11}/\text{m}^2\text{-s-ster}$. Objective value is in parentheses. Upper flux level (threshold) set by experience from TIROS. Lower bound is set by the typical dynamic range of a solid-state detector and the total flux precision requirement,
- Reduce the number of required energy bands from 8 to 6 to simplify instrument design,
- New objective requirement is to provide total dose measurements.

EDR4.1.6.7.13 - Solar & Galactic Cosmic Ray Particles

- Delete requirement for mass discrimination. Concentrate on energetic protons within the energy range of 10 MeV -to- 300 (400) MeV and flux levels from $5\times 10^3 - 2\times 10^9 /\text{m}^2\text{-s-ster}$. This flux range is consistent with moderate-to-high event levels,
- Clarify requirement on the number of energy bins: 6(8),
- Rename “Solar and Galactic Ray Particles” to “Energetic Ions”,
- Add objective measurement for the Linear Energy Transfer (L.E.T.) over the range 1(0.1) to 50 (100) $\text{MeV-cm}^2\text{-mg}^{-1}$,
- Determination of alpha particles and other heavy ions is left as an objective measurement.

4.4 World Magnetic Model

During the course of the Task 2 study the requirements basis for a magnetometer was continually questioned. Neither the Ionospheric Effects -Scintillation working group or the Atmospheric Density - Orbital Drag working group could identify a strong user

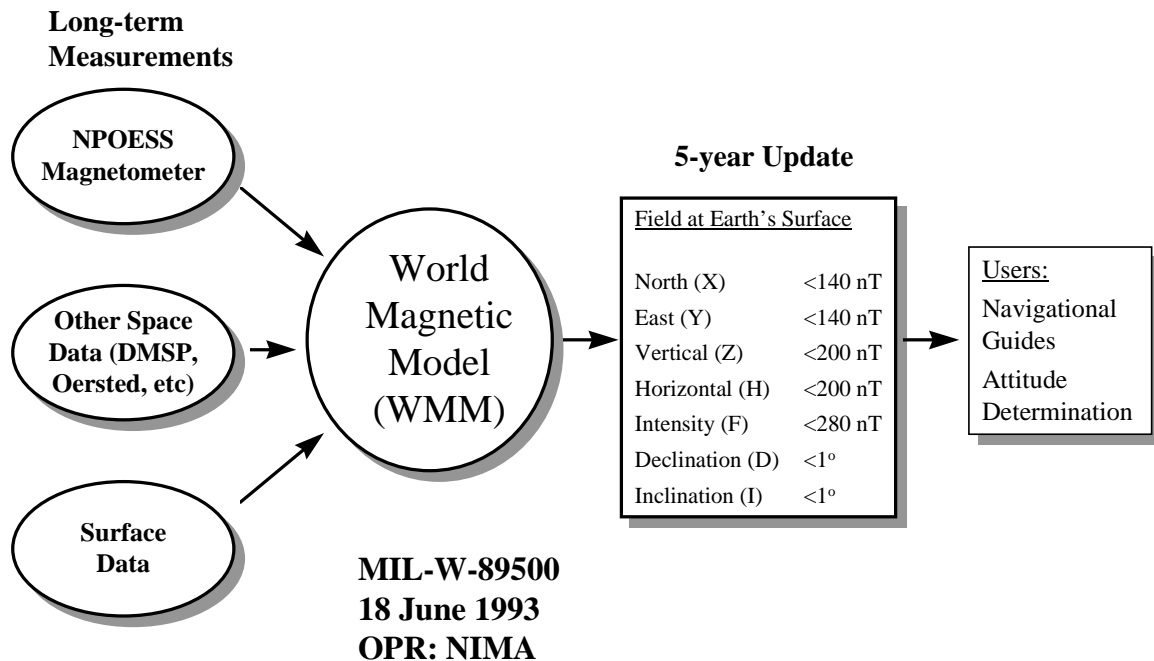


Figure 14. CONOP supporting the WMM.

need to support the Geomagnetic Field EDR. The Satellite Design and Anomaly

Resolution working group did identify a user need but the requirements on accuracy and precision were fairly modest. The SESG found, however, that there was a specific user

need for accurate magnetic field measurements on NPOESS to support the World

Magnetic Model. Requirements for magnetic data originate within the office of the

Commander, Space and Naval Warfare Systems Command (SPAWARSSCOM) to

support the operations of the Surveillance Towed Array Sensor System (SURTASS) and

support GPS-assisted waypoint bearing. These data are incorporated into the 5-year

updates to the World Magnetic Model in accordance with MIL-W-89500 - see Figure 14.

Responsibility for the WMM has been assigned to the U.S. Geological Survey and the

organizational point-of-contact is Mr. John Quinn (303-273-8475). Mr Quinn provided

the following sensor specifications needed to support the WMM data needs:

- Vector Magnetometer
 - Range: 60,000 nT (each axis)
 - Resolution/Sensitivity: < 2 nT/axis
 - Absolute Attitude Determination: <1 arc-min
 - Absolute Accuracy: <15 nT/axis
- Scalar Magnetometer
 - Range: 10,000 nT to 65,000 nT
 - Resolution/Sensitivity: <0.1 nT
- Spacecraft Magnetic Noise
 - At position of scalar/vector magnetometers: 15 nT
- Other Parameters to be Monitored
 - Vector Magnetometer's Sensor Temperature to within 0.1 °C
 - Vector Magnetometer's Electronics Temperature to within 0.1 °C
 - Scalar Magnetometer's Sensor Temperature to within 0.1 °C
 - Scalar Magnetometer's Electronics Temperature to within 0.1 °C
 - Solar Panel Current to within 0.1 A
 - Torquing Coils Current to within 0.1 A
 - Time & Duration of Data Transmission

These requirements were used to specify the Geomagnetic Field EDR in section 5. The SESG recognizes that the requirements, mostly magnetic cleanliness, for a magnetometer on NPOESS to support the WMM may be difficult to accommodate.

5. OVERALL EDR RECOMMENDATIONS

The overall EDR recommendations by the SESG are contained in this section. The changes to the IORD I that we recommend include renaming 5 of the 17 original space EDRs, major rewrites on 4, deletion of 3, and the proposed addition of 1. Relative to this additional EDR for neutral winds the overall consensus of the SESG is that this should be offered as an objective EDR at this time since this data is *useful* for low-latitude scintillation prediction and fundamental to an, as yet, *unproven technique* for first principles modeling of the neutral atmosphere. The overall changes to the space EDRs for NPOESS are summarized in Figure 15 (compare to Table 1). The detailed changes

recommended, with justification, are provided in the briefing slides, copies of which are reproduced here. The changes in the EDRs from the IORD I are clearly indicated by italics. Objective values in shown in parentheses.

SPACE EDRs (Revised)	IORD-1	STATUS
Auroral Boundary	4.1.6.7.1	relaxed accuracy
Auroral Energy Deposition	4.1.6.7.2	renamed, relaxed p ⁺ & e ⁻ , added <E>
Auroral Imagery	4.1.6.7.3	major rewrite, generalized
Electric Field	4.1.6.7.4	clarified
Electron Density Profile	4.1.6.7.5	renamed, major rewrite
Geomagnetic Field	4.1.6.7.6	relaxed precision & accuracy
In-situ Ion Drift Velocity	4.1.6.7.7	delete - redundant
In-situ Plasma Density	4.1.6.7.8	delete - merged
In-situ Plasma Fluctuations	4.1.6.7.9	clarified, relaxed resolution
In-situ Plasma Temperature	4.1.6.7.10	specify T _i & T _e
Ionospheric Scintillation	4.1.6.7.11	revised accuracy, drop precision
Neutral Density Profile	4.1.6.7.12	renamed, major rewrite
Medium Energy Charged Particles	4.1.6.7.13	renamed, separate p ⁺ & e ⁻ , relax prec
Energetic Ions	4.1.6.7.14	renamed, major rewrite
Solar Extreme Ultra Violet Flux	4.1.6.7.15	revised, non-NPOESS?
Supra-thermal through Auroral Energy Particles.	4.1.6.7.16	extend range
Upper Atmospheric Airglow	4.1.6.7.17	delete - not fundamental
Neutral Wind	new	new

Figure 15. List of Recommended Changes to the IORD I Space EDRs.

Within the CONOPS of each of the Working Groups, the EDRs were rated for whether a particular EDR was; 1) operationally viable today, 2) had a demonstrated need but additional work is needed to establish CONOPS traceability and/or viability, or 3) useful to research related to an operational need. The EDRs were also assessed for their mission impact; either high, medium, or low. These results are summarized in Figure 16. It should be noted that the SESG was specifically cautioned not to provide a summary prioritization of the EDRs as a recommendation to the JARG. Thus the results of the working group, as presented in Figure 16, are submitted to the JARG without prejudice.

SES EDRs	WG1	WG2	WG3	TALLY
Auroral Boundary	I/High	N.R.	I/High	I/High
Auroral Energy Deposition	I/High	III	I/Mod	I/High
Auroral Imagery	I/Mod	N.R.	N.R.	I/Mod
Electric Field	I/High	III	II/Mod	I/High
Electron Density Profile	II/High	III	I/Mod	I/High
Geomagnetic Field	N.R.	N.R.	II/Low	I/High*
In-situ Drift Velocity	-	-	-	-
In-situ Plasma Density	-	-	-	-
In-situ Plasma Fluctuations	II/High	N.R.	N.R.	II/High
In-situ Plasma Temperatures	II/Low	N.R.	N.R.	II/Low
Ionospheric Scintillation	II/Low	N.R.	N.R.	II/Low
Neutral Density Profile	III	II/High	II/Low	II/High
Medium Energy Charged Particles	I/Low	N.R.	I/Mod	I/Mod
Energetic Ions	N.R.	N.R.	II/Low	II/Low
Solar Extreme Ultra Violet Flux	I/Mod	III	N.R.	I/Mod
Supra-thermal / Auroral Energy Part.	III	N.R.	I/High	I/High
Upper Atmospheric Airglow	-	-	-	-
Neutral Wind	II/High	III	N.R.	II/High

*Geomagnetic field has identified CONOPS and high relevancy for the World Magnetic Model

Class Definitions (N.R. means not rated by this WG):

- I Operationally viable with demonstrated CONOPS traceability
- II Demonstrated need but limited CONOPS traceability or viability
- III Additional research required to assess viability

Mission Impact Assessment:

- High Measurement of this EDR is of fundamental importance
- Mod Secondary importance or EDR can be obtained elsewhere
- Low EDR does not have a significant impact on this mission area

Figure 16. Working Group assessments of the NPOESS EDRs.

6. FINAL REMARKS

This report represent the final output of Task 2 for the SESG. The recommended changes to the IORD I are forwarded to the JARG for their consideration and action. It is expected that the JARG will review this report and submit their approved recommendations to the SUAG for implementation as requirements for the NPOESS. The SES SRD will incorporate the changes as approved by the SUAG.

APPENDIX

SESG OVERVIEW



SPACE ENVIRONMENT STEERING GROUP (SESG)

REPORT
TO THE
INTEGRATED PROGRAM OFFICE (IPO)
FOR THE
NATIONAL POLAR-ORBITING OPERATIONAL
ENVIRONMENTAL SATELLITE SYSTEM
(NPOESS)

TASK 2 OUTBRIEF
05 MAY 98



PURPOSE

- **Present Task 2 outbrief to the NPOESS/IPO**
- **Request authorization to submit Task 2 product to the JARG**
- **Request authorization to proceed to Task 3**



WHAT WE HAVE DONE SO FAR

- **Defined traceability to user (DOD, DOC, NASA) space environmental needs**
- **Identified utilization of NPOESS EDRs in user CONOPS, current, near-term, future**
- **Provided recommended IORD-1 changes in the Space Environmental EDRs for NPOESS**
- **Prioritized IORD-1 Space Environmental EDRs**



WHERE WE WANT TO GO

Request authorization to:

- **Release Task 2 results to the JARG**
 - **Please advise: When is the right time?**
 - **Please advise: Where are the minefields?**
- **Proceed into Task 3**
 - **Product: sensor performance specs**
 - **Product: notional sensor suite**
 - **Product: draft RFP / BTI**



BRIEFING OUTLINE

- ➔ **Overview & Summary**
- Working Group Reports**
- Recommended IORD Changes**



SESG RATIONALE

- **Space environmental requirements met by an evolving system of ground and space-based assets**
- **Some requirements may not be fully traceable to an end-user CONOPS**
- **Some requirements can be met with proven sensors**

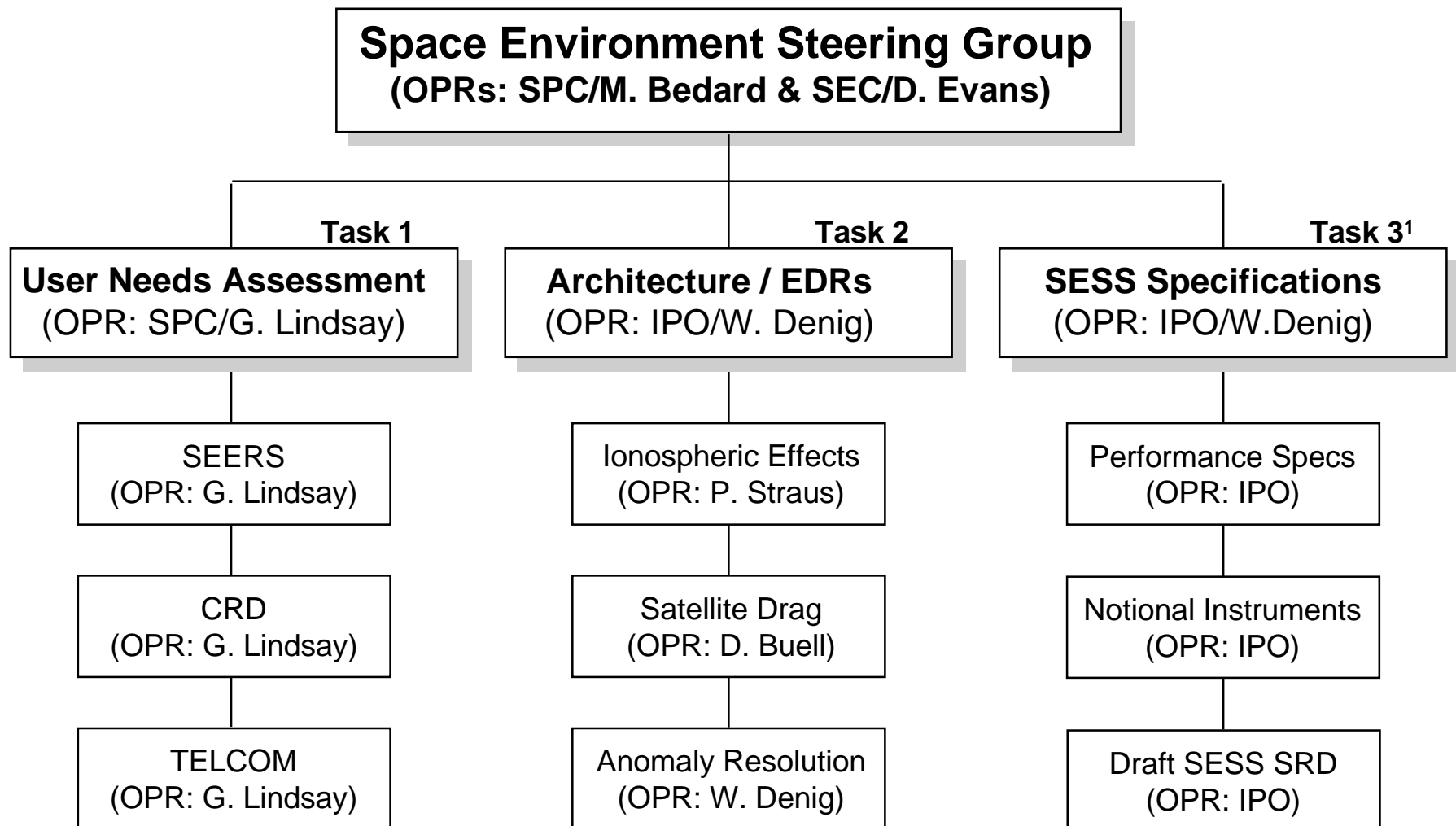


SESG TASKING

- TASK 1 → Identify user applications and needs for space environmental support**
- TASK 2 → Examine the space environmental support architecture but focussed on the NPOESS**
- TASK 3 → Draft performance specifications for the NPOESS Space Environment Sensor Suite (SESS)**



SESG STRUCTURE



¹Pending Authorization to Proceed



SESG PROCESS

TASK 1

USER SURVEY



SEERS



BRIEF
RESULTS



AFSPC
CRD

**YOU ARE
HERE**



TASK 2

ARCHITECTURE



WORKING
GROUPS



CONOPS



BRIEF
JARG

TASK 3¹

SENSOR PERF



PERF
SPECS



NOTIONAL
SENSORS



DRAFT
RFP

¹Pending Authorization to Proceed



TASK 1: USER SURVEY

USER: DOD

Radar Operations	_____	_____	Solar noise and auroral clutter specification
		_____	Range error correction, Scintillation
HF Communications	_____		MUF/FOT, PCA event, Shortwave fades
Navigation/Satellite Communications	_____	_____	Single frequency GPS accuracy
		_____	Scintillation forecast/specification
Classified	_____		Arbitrary slant path TEC
Altimetry, Single Frequency	_____		Ionospheric corrections for sea surface heights
Satellite Design and Anomaly Analysis	_____	_____	Radiation hazards for manned spaceflight & high flyers
		_____	Long-term representative data sets for satellite design
		_____	Space environment data for anomaly resolution
Space Surveillance	_____		Accurate neutral density forecast/specification

USER: DOC

Satellite Operators	_____		Space environmental parameters affecting satellite ops
Power Companies	_____		Distribution and intensity of geomagnetic field variations
NASA	_____		Radiation dose(man) , polar cap boundary, satellite drag
FAA	_____		Ionospheric impacts on communications and navigation
NOAA	_____		Radiation effects on satellite, mag field variations, drag
Ham Radio Operators	_____		Global ionospheric disturbances
Geo-Prospecting	_____		Locations of geomagnetic field variations
Science Community	_____		Space environment effects on experiments, contamination
International Forecast Cntrs (Japan. Australia, etc)	_____		Global situational awareness

USER: NASA

Manned Spaceflight	_____		Radiation Dose
Satellite Lifetimes	_____		Orbital drag forecasts



OBJECTIVES/PARTICIPANTS

TASK 2: ARCHITECTURE

Working Group Objectives¹

- Document existing CONOPS (data, models, methods)
- Identify future CONOPS
- Determine contributions from NPOESS
- Prioritize and update NPOESS EDRs in IORD-1

-Working Group 1- Ionospheric Effects & Scintillation

Paul Straus, Aerospace (Lead)
Gretchen Lindsay, Aerospace (Co)
Dave Anderson, AFRL
Santi Basu, AFRL
Greg Bishop, AFRL
Terry Bullett, AFRL
Ken Davies, NOAA/SEC
Dave Evans, NOAA/SEC
Joe Kunches, NOAA/SEC
Pat Lunney, 76SOPS
Bob Meier, NRL
Ed Weber, AFRL
Brian Wilson, JPL

-Working Group 2- Satellite Drag & Neutral Density

Diane Buell, IPO/MITRE (Lead)
Tim Fuller-Rowell, NOAA/SEC
Frank Marcos, AFRL
Jerry Owens, NASA/MSFC
Mike Picone, NRL
Mark Storz, AFSC/SWC
Richard Walterscheid, Aerospace

-Working Group 3- Satellite Design & Anomaly Resolution

Bill Denig, IPO (Lead)
Phil Anderson, Aerospace
Steve Cahanin, 50 WS/DO
Dave Evans, NOAA/SEC
Harry Koons, Aerospace
Gary Mullen, AFRL
Steve Pearson, NASA/MSFC
Dave Speich, NOAA/SEC
Michelle Thomsen, LANL

¹Separate working group reports are attached.



IOR-1 IMPACTS - BRIEF

TASK 2: ARCHITECTURE

IOR-1 changes recommended by WGs:

- Renamed 5 of 17 SES assigned EDRs
- Tweaked most - either clarified or adjusted a parameter
- Major rewrite on 4: EDP / NDP / Mag Field / Cosmic Rays
- Dropped 3: Ion Drift (redundant), Ion density (merged) and airglow (not fundamental)
- Added 1: Objective for neutral wind



IORD-1 IMPACTS - DETAILS

TASK 2: ARCHITECTURE

SES EDRs	IORD-1	STATUS
Auroral Boundary	4.1.6.7.1	relaxed accuracy
Auroral Energy Deposition, Total	4.1.6.7.2	relaxed p ⁺ & e ⁻ , renamed, added <E>
Auroral Imagery	4.1.6.7.3	generalized, non-sensor specific
Electric Field	4.1.6.7.4	clarified
Electron Density Profiles/Ionospheric Specification	4.1.6.7.5	revised scheme, renamed
Geomagnetic Field	4.1.6.7.6	relaxed precision & accuracy
In-situ Ion Drift Velocity	4.1.6.7.7	redundant, drop EDR
In-situ Plasma Density	4.1.6.7.8	merged, drop EDR
In-situ Plasma Fluctuations	4.1.6.7.9	clarified, relaxed resolution
In-situ Plasma Temperature	4.1.6.7.10	specify T _i & T _e
Ionospheric Scintillation	4.1.6.7.11	revised accuracy, drop precision
Neutral Density Profile/Neutral Atmospheric Specification	4.1.6.7.12	revised scheme, renamed
Radiation Belt and Low Energy Solar Particles	4.1.6.7.13	separate p ⁺ & e ⁻ , relax prec.
Solar and Galactic Cosmic Ray Particles	4.1.6.7.14	renamed, relax mass discrimination
Solar Extreme Ultra Violet Flux	4.1.6.7.15	revised, non-NPOESS?
Supra-thermal through Auroral Energy Particles.	4.1.6.7.16	extend range
Upper Atmospheric Airglow	4.1.6.7.17	not fundamental, drop EDR
Neutral Wind	new	new



RENAMED EDRs

TASK 2: ARCHITECTURE

Auroral Energy Deposition, Total → Auroral Energy Deposition

Electron Density Profiles /
Ionospheric Specification → Electron Density Profile

Neutral Density Specification /
Neutral Atmospheric Specification → Neutral Density Profile

Radiation Belt and Low Energy
Solar Particles → Medium Energy Charged Particles

Solar and Galactic Cosmic Ray
Particles → Energetic Ions



WG ASSESSMENTS

TASK 2: ARCHITECTURE

SES EDRs	WG1	WG2	WG3	TALLY
Auroral Boundary	I/High	N.R.	I/High	I/High
Auroral Energy Deposition	I/High	III	I/Mod	I/High
Auroral Imagery	I/Mod	N.R.	N.R.	I/Mod
Electric Field	I/High	III	II/Mod	I/High
Electron Density Profile	II/High	III	I/Mod	I/High
Geomagnetic Field	N.R.	N.R.	II/Low	II/Low
In-situ Drift Velocity	-	-	-	-
In-situ Plasma Density	-	-	-	-
In-situ Plasma Fluctuations	II/High	N.R.	N.R.	II/High
In-situ Plasma Temperatures	II/Low	N.R.	N.R.	II/Low
Ionospheric Scintillation	II/Low	N.R.	N.R.	II/Low
Neutral Density Profile	III	II/High	II/Low	II/High
Medium Energy Charged Particles	I/Low	N.R.	I/Mod	I/Mod
Energetic Ions	N.R.	N.R.	II/Low	II/Low
Solar Extreme Ultra Violet Flux	I/Mod	III	N.R.	I/Mod
Supra-thermal / Auroral Energy Part.	III	N.R.	I/High	I/High
Upper Atmospheric Airglow	-	-	-	-
Neutral Wind	II/High	III	N.R.	II/High

Class Definitions (N.R. means not rated by this WG):

- I Operationally viable with demonstrated CONOPS traceability.
- II Demonstrated need but limited CONOPS traceability or viability.
- III Additional research required to assess viability.

Mission Impact Assessment:

- High Measurement of this EDR by NPOESS is of fundamental importance
- Mod Secondary importance or EDR can be obtained elsewhere
- Low EDR does not have a significant impact on this mission area



EDR PRIORITIES

TASK 2: ARCHITECTURE

GROUP 1 Highest Value	Auroral Boundary Auroral Energy Deposition Electron Density Profile Electric Field Geomagnetic Field¹ Supra-thermal to Auroral Energy Particles
GROUP 2	Auroral Imagery In-situ Fluctuations Medium Energy Charged Particles Neutral Density Profile Solar Extreme Ultra Violet Flux <i>Neutral Winds</i>
GROUP 3	In-situ Plasma Temperatures Ionospheric Scintillation Energetic Ions

Groupings: 1=[I/H]; 2=[I/M, II/H]; 3=[II/L]

¹Note: DMA represents the DOD regarding requirements for magnetic data to support generation of the WMM (Epoch 2000 and beyond). - Ltr dtd 31JUL96, DMA. Mr John Quinn (USGS, 303 273-8475) identified as POC.



REVIEW

TASKS 1 & 2

- **Defined traceability to user (DOD, DOC, NASA) space environmental needs (Task 1)**
- **Identified utilization of NPOESS EDRs in user CONOPS, current, near-term, future (Task 2)**
- **Provided recommended IORD-1 changes in the Space Environmental EDRs for NPOESS (Task 2)**
- **Prioritized IORD-1 Space Environmental EDRs (Task 2)**



SUMMARY

Request authorization to:

- **Release Task 2 results to the JARG**
 - **Please advise: When is the right time?**
 - **Please advise: Where are the minefields?**
- **Proceed into phase 3**
 - **Product: sensor performance specs**
 - **Product: notional sensor suite**
 - **Product: draft RFP / BTI**



NEXT STEP

TASK 3: ARCHITECTURE

Space Environment Sensor Suite Sensor Requirements Document

for

National Polar-orbiting Operational
Environmental Satellite System
Spacecraft and Sensors

DRAFT

Prepared by

Associate Directorate for Acquisition
NPOESS Integrated Program Office

- **Forms the basis for the NPOESS SES RFP**
- **Produced as either a single document or multiple documents for the various sensor suite elements**
- **Current target date of preliminary RFP release is Mar '99**



BRIEFING OUTLINE

Overview & Summary



Working Group Reports

Recommended IORD Changes



IONOSPHERIC EFFECTS AND SCINTILLATION

Task 2 - EDR Assessment & Validation

Ionospheric Working Group

Team Members

Paul Straus, Aerospace
Gretchen Lindsay, Aerospace
Dave Evans, NOAA/SEC
Joe Kunches, NOAA/SEC
Ken Davies, NOAA/SEC
Pat Lunney, 76SOPS
Brian Wilson, JPL

Dave Anderson, AFRL
Ed Weber, AFRL
Santi Basu, AFRL
Terry Bullett, AFRL
Greg Bishop, AFRL
Bob Meier, NRL



Briefing Outline

IONOSPHERIC EFFECTS AND SCINTILLATION

- Task 2 Objectives
 - User Areas & Requirements Assessed
 - Concepts of Operation
 - EDR Prioritization
 - EDR Changes



Task 2 Objectives

IONOSPHERIC EFFECTS AND SCINTILLATION

- **Document Existing CONOPS (Data, Models, Methods)**
- **Identify Future CONOPS**
- **Determine Contributions From NPOESS**
- **Prioritize NPOESS EDRs**
- **Validate EDR Parameter Values**



Briefing Outline

IONOSPHERIC EFFECTS AND SCINTILLATION

Task 2 Objectives

→ User Areas & Requirements Assessed

Concepts of Operation

EDR Prioritization

EDR Changes



Mission Areas Addressed

IONOSPHERIC EFFECTS AND SCINTILLATION

- **DOD**
 - » Radar operations
 - » Satellite Communications/Navigation
 - Low latitude
 - High latitude
 - Single frequency GPS support
 - » HF Communications
 - » Single Frequency Altimetry corrections
 - » National Programs
- **DOC**
 - » Global Situational Awareness supporting
 - Communications
 - Navigation
 - Power companies (ground induced currents)



Areas Not Driving NPOESS Requirements I

IONOSPHERIC EFFECTS AND SCINTILLATION

- Solar Radio Noise Impacts on Radar Systems
 - » Ground-based RSTN meets need for alerts
- Most HF Communications
 - » Current support capability seen as adequate
 - » Automatic Link Establishment (ALE) technology reduces future needs for ionospheric support
 - » Potential use of ionospheric data to allow



Areas Not Driving NPOESS Requirements II

IONOSPHERIC EFFECTS AND SCINTILLATION

- Single Frequency Altimetry
 - » Anticipate use of dual frequency altimeters in NPOESS era (e.g., as in NPOESS CARD)
 - An NPOESS altimeter would be an additional source of ionospheric information
- Power Company Support
 - » GIC predictions require data from non-LEO spacecraft and ground sensors



Basic Operational Requirements I

IONOSPHERIC EFFECTS AND SCINTILLATION

● Radar Systems

- » Is a target being tracked a false alarm induced by auroral clutter?
- » What ionospheric corrections should be applied to space tracking radar observations?
 - 5 TEC unit error (current capability estimated at solar minimum) is considered acceptable
 - Ray bending at low elevation angles and larger ionospheric specification errors at solar maximum lead to degraded performance



Basic Operational Requirements II

IONOSPHERIC EFFECTS AND SCINTILLATION

- Satellite Communications (DOD & DOC)
 - » Accurate predictions of scintillation-induced communications outages
 - » Capability to assess whether scintillation played a role in communications outages (anomaly assessment)
 - » DOC requires less stressing “situational awareness”
- GPS Navigation (DOD & DOC)



Basic Operational Requirements III

IONOSPHERIC EFFECTS AND SCINTILLATION

- National Programs
 - » Near real time specification of ionospheric total electron content along an arbitrary slant path from ground to an arbitrary altitude
 - Stressing objective of 2-3 TEC units
 - Arbitrary slant path requirement together with accuracy objective implies need for profile specification
- High Latitude HF Communications
 - » Specification of Polar Cap Absorption events



Briefing Outline

IONOSPHERIC EFFECTS AND SCINTILLATION

Task 2 Objectives

User Areas & Requirements Assessed

→ Concepts of Operation

EDR Prioritization

EDR Changes



EDR Prioritization Scheme

IONOSPHERIC EFFECTS AND SCINTILLATION

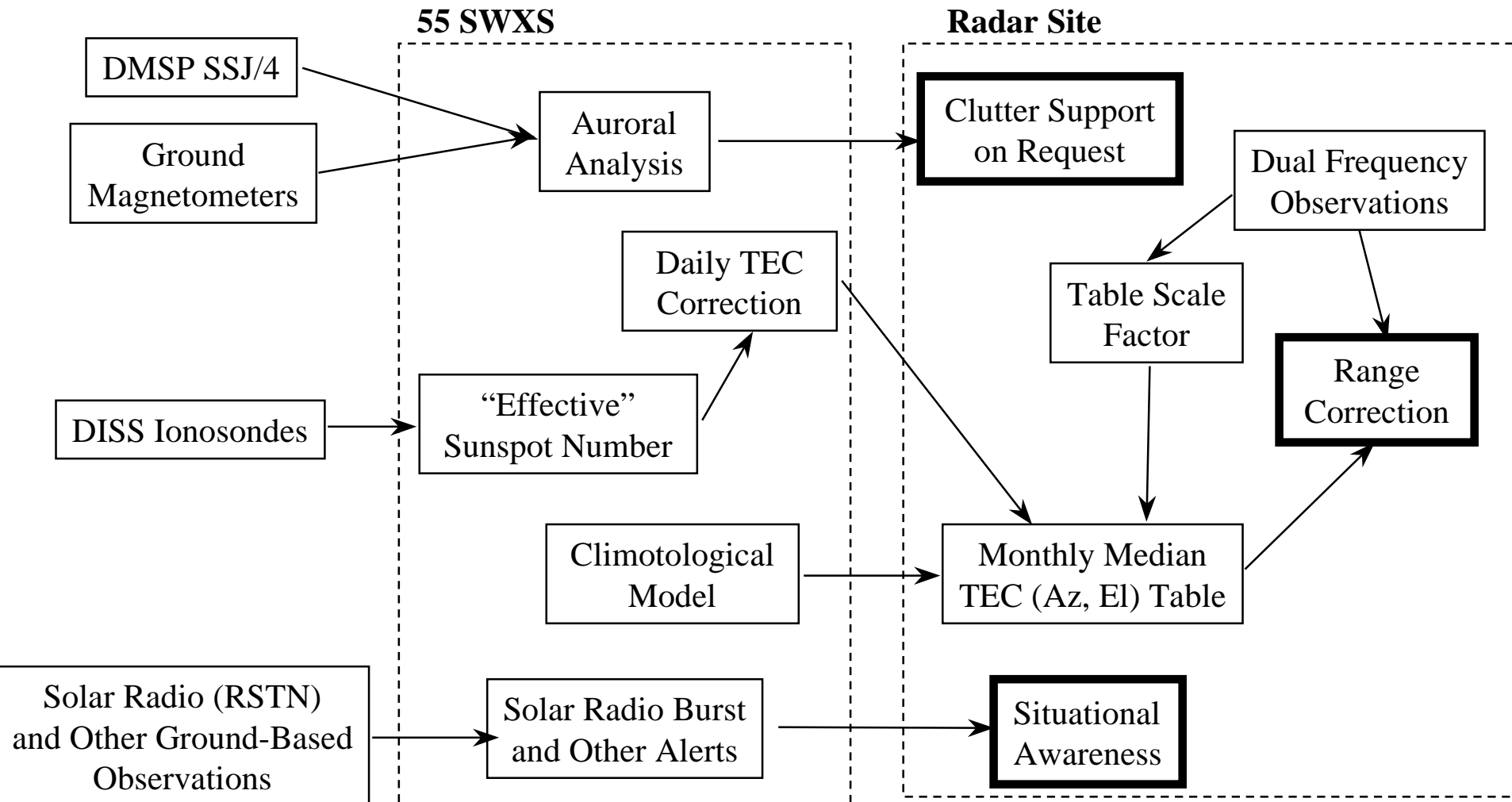
- **Class I:** Operationally Viable Solution With Demonstrated Requirements Traceability
- **Class II:** Demonstrated Operational Need But One Or More Of The Following Apply
 - » Requirements traceability uncertain
 - » CONOPs uncertain
 - » Feasibility uncertain
- **Class III:** Research Related To Meeting User's Needs
- **Class IV:** EDR Is Derived From Other EDRs
- **Class V:** No Need For This EDR

Class I & II EDRs Rated For Mission Impact (Low/Med/High)



Current CONOPS for Radar Operations*

IONOSPHERIC EFFECTS AND SCINTILLATION

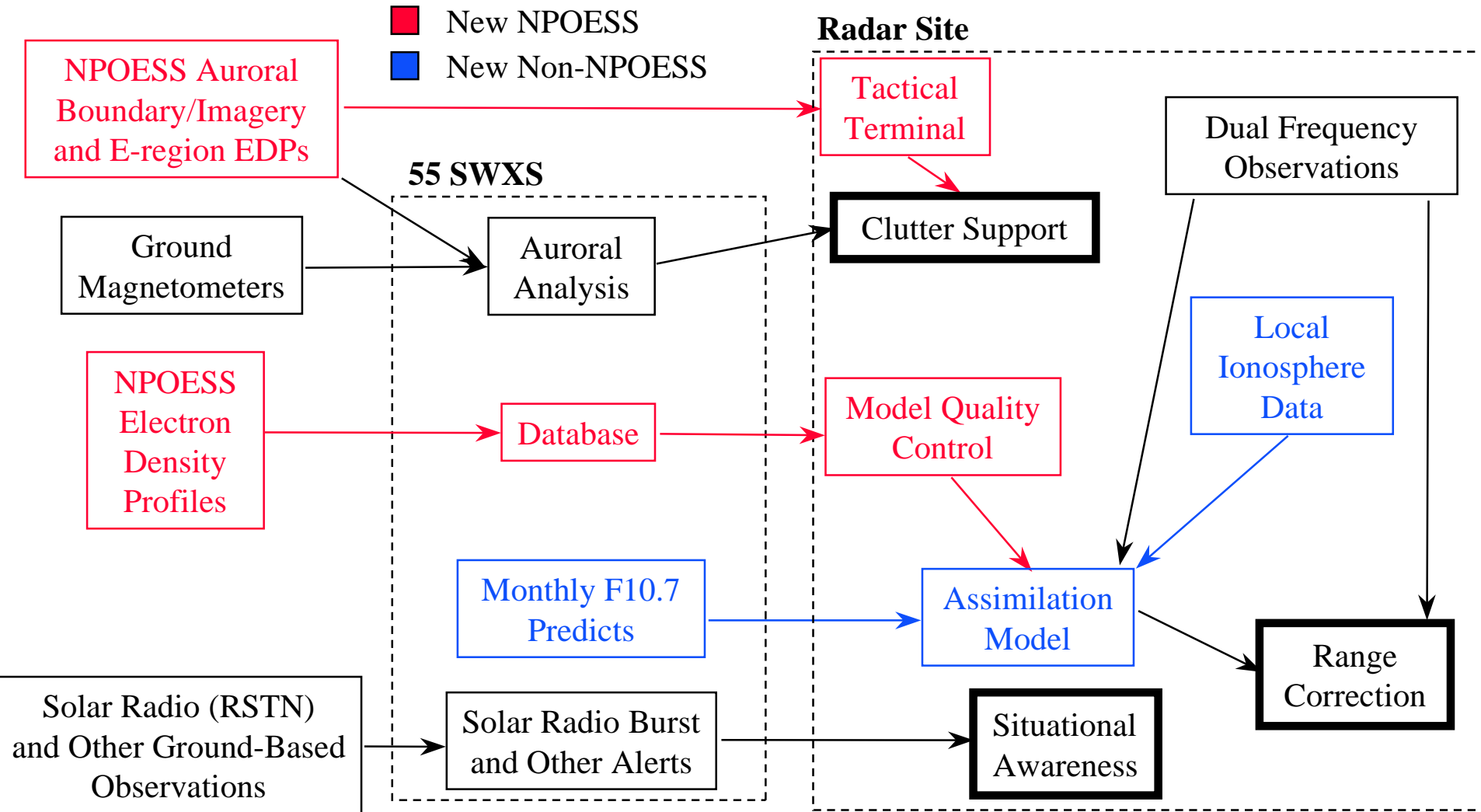


*Except Scintillation Effects: Discussed Later



Future CONOPS for Radar Operations*

IONOSPHERIC EFFECTS AND SCINTILLATION



*Except Scintillation Effects: Discussed Later



Future Radar CONOPS Issues I

IONOSPHERIC EFFECTS AND SCINTILLATION

- **Auroral Clutter Issues**
 - » Auroral Boundary knowledge required to provide qualitative anomaly assessments and situational awareness (Class I, High Impact)
 - » Near real time Imagery allows quick evaluation of clutter impacts, but coverage is not 100% except at high latitudes (Class I, Medium Impact)
 - » Clutter levels may be quantified by knowledge of E-region electron densities and possibly Electric Fields, but additional research is required (Class II, Medium Impact)



Future Radar CONOPS Issues II

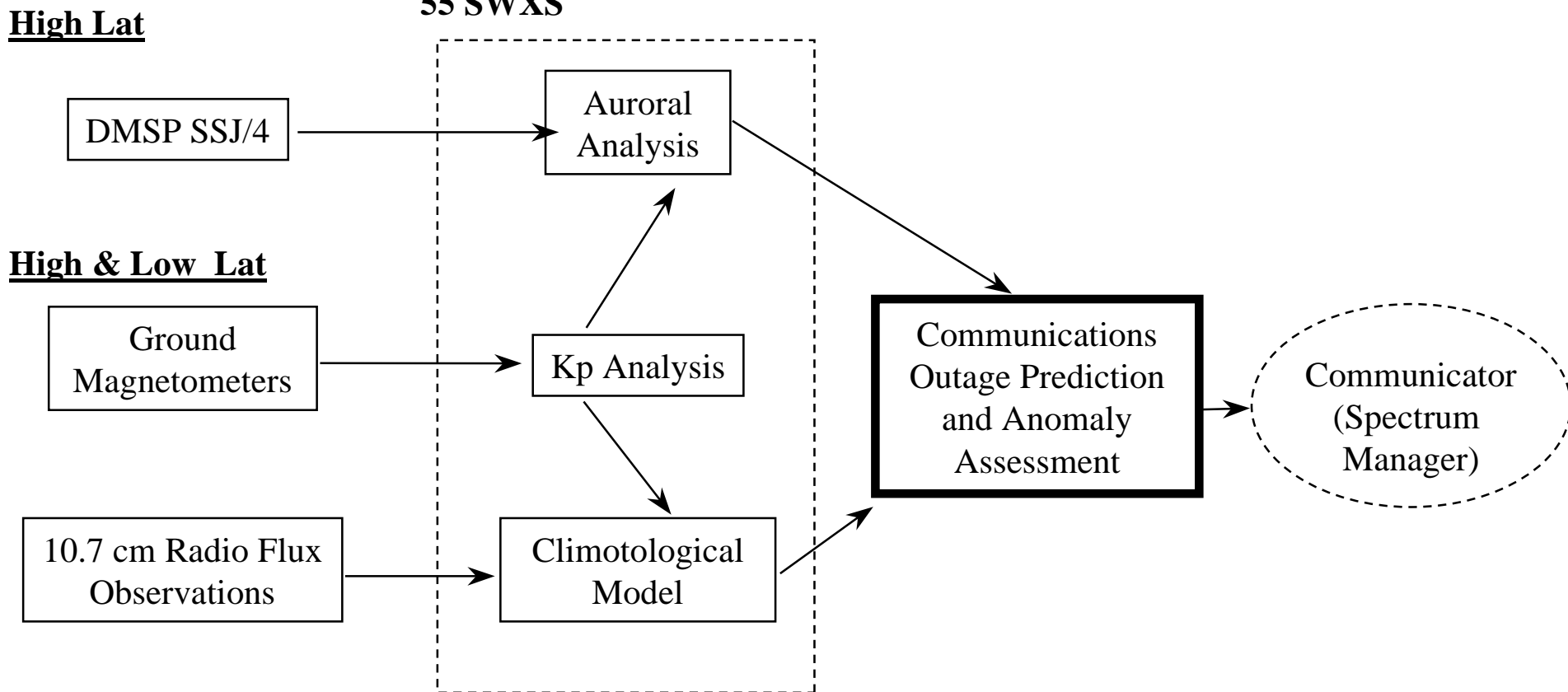
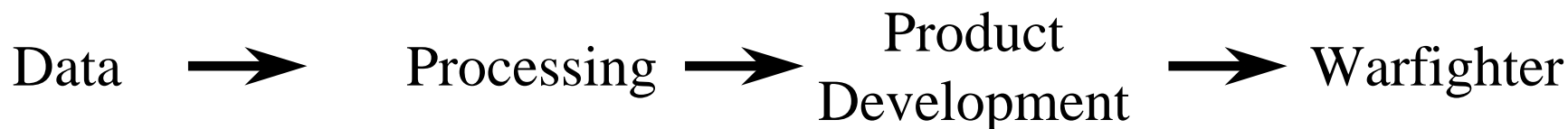
IONOSPHERIC EFFECTS AND SCINTILLATION

- **Ionospheric Range Corrections Primarily Obtained From Local, Non-NPOESS, Data Sources**
 - » Prototype system under development for Altair
 - » Advanced system may require regional ground-based data sources
 - » NPOESS EDPs useful for local model validation (Class I, Low Impact)
 - » Added value of potential advanced CONOPS using global model at 55SWS is uncertain, but this may be only way to fully meet requirements under stressing conditions (solar max, geomagnetically active). Did not use this CONOPS to drive NPOESS requirements.



Current CONOPS for Satellite Communications

IONOSPHERIC EFFECTS AND SCINTILLATION



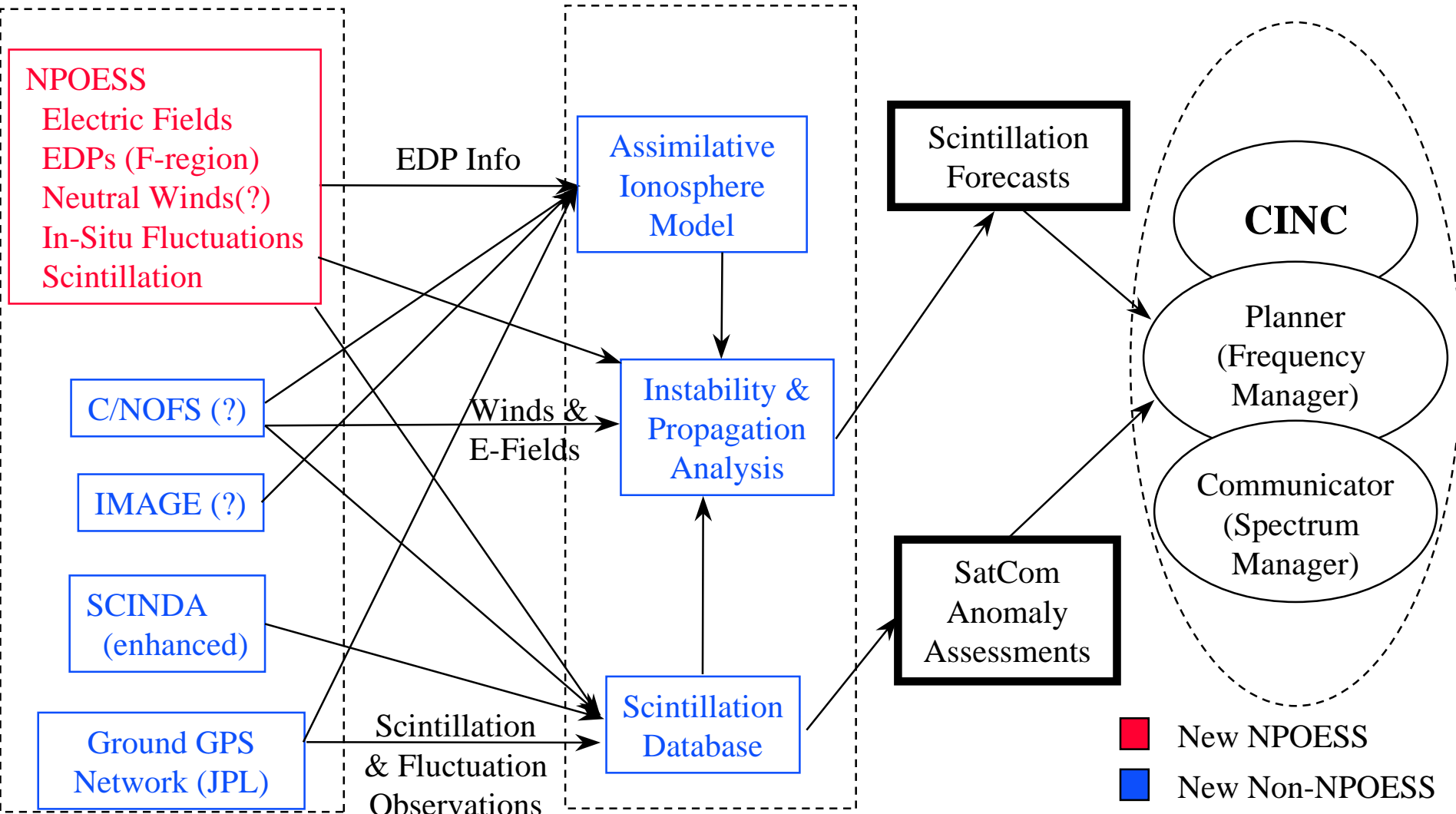


Future CONOPS for Satellite Communications

(Low Latitude Support)

IONOSPHERIC EFFECTS AND SCINTILLATION

Data Sources





Future CONOPS for Satellite Communications/Radars

(High Latitude Support)

IONOSPHERIC EFFECTS AND SCINTILLATION

Data Sources

NPOESS

Auroral Boundary
Electric Fields
EDPs (F-region)
In-Situ Fluctuations
Scintillation

EDP Info

E-Fields

Scintillation
& Fluctuation
Observations

55 SWXS

Plasma
"Patch"
Identification

High Latitude
Convection
Model

Drift
Analysis

Scintillation
Database

Scintillation
Forecasts

SatCom
Anomaly
Assessments

Radar Sites

CINC

Planner
(Frequency
Manager)

Communicator
(Spectrum
Manager)

■ New NPOESS
■ New Non-NPOESS



Future SatCom CONOPS Issues

(Low Latitude)

IONOSPHERIC EFFECTS AND SCINTILLATION

- **Current Outage Prediction Capability Is Very Poor**
- **Predictive Capability Under Development Using DMSP In-Situ Observations Will Be Improved With EDPs**
- **NPOESS Can Provide Unique Latitudinal EDP Cuts In Equatorial Region Not Provided By Other Systems**
- **High Sensitivity E-Fields & Neutral Winds Desired**
- **Low Latitude Predictive Capability Still Under Development (Class II, High Impact)**
- **Scintillation Measurements From Non-NPOESS Systems (GPS, Comm. Sats) & NPOESS Polar Orbit Reduce Benefit of Scintillation EDR (Class III)**



Future SatCom/Radar CONOPS Issues

(High Latitude)

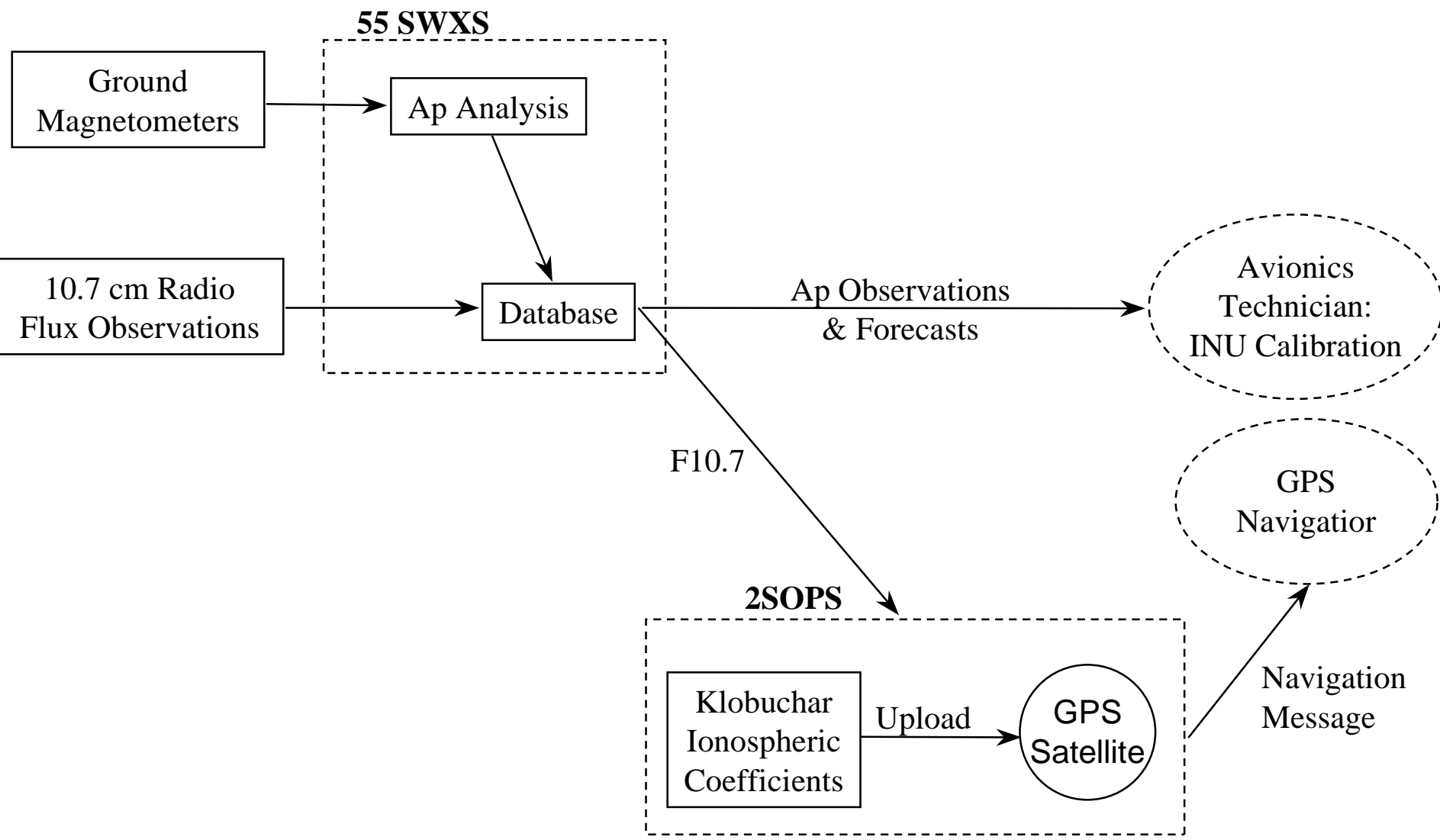
IONOSPHERIC EFFECTS AND SCINTILLATION

- **High Latitude (Class II, Medium Impact) Vs. Low**
 - » May be more difficult to develop predictive capability
 - » Scintillation is somewhat weaker
 - » Region is lower interest
- **F-Region Scintillation Can Mask Small Single Targets For Radars**
- **Other Sources Of Scintillation Data Reduce Need For Scintillation EDR For SatCom (Class III), But EDR May Be Useful As Calibration Point For Radars (Class II, Low Impact)**



Current CONOPS for Navigation

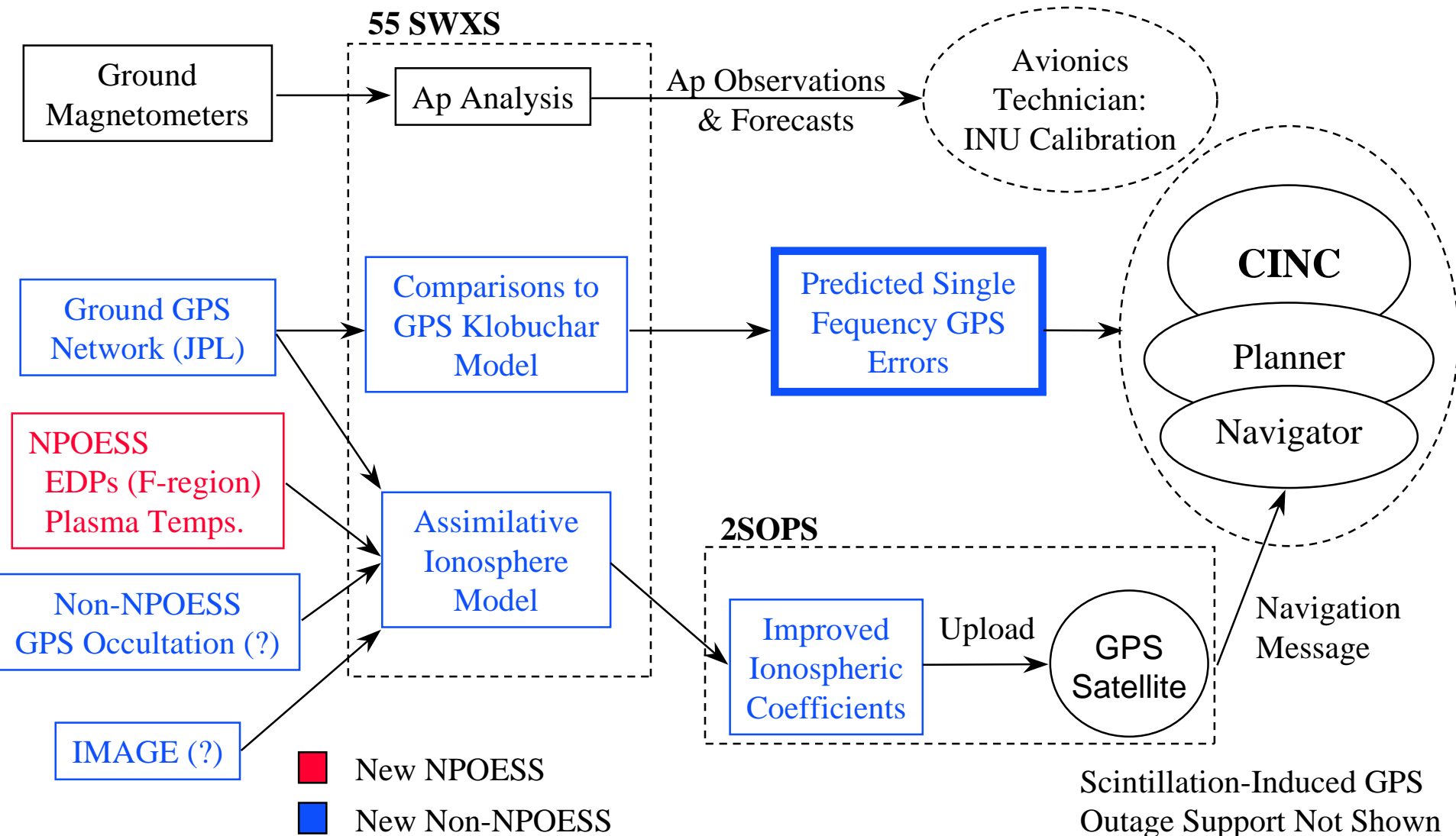
IONOSPHERIC EFFECTS AND SCINTILLATION





Future CONOPS for Navigation

IONOSPHERIC EFFECTS AND SCINTILLATION





Future Navigation Support CONOPS Issues

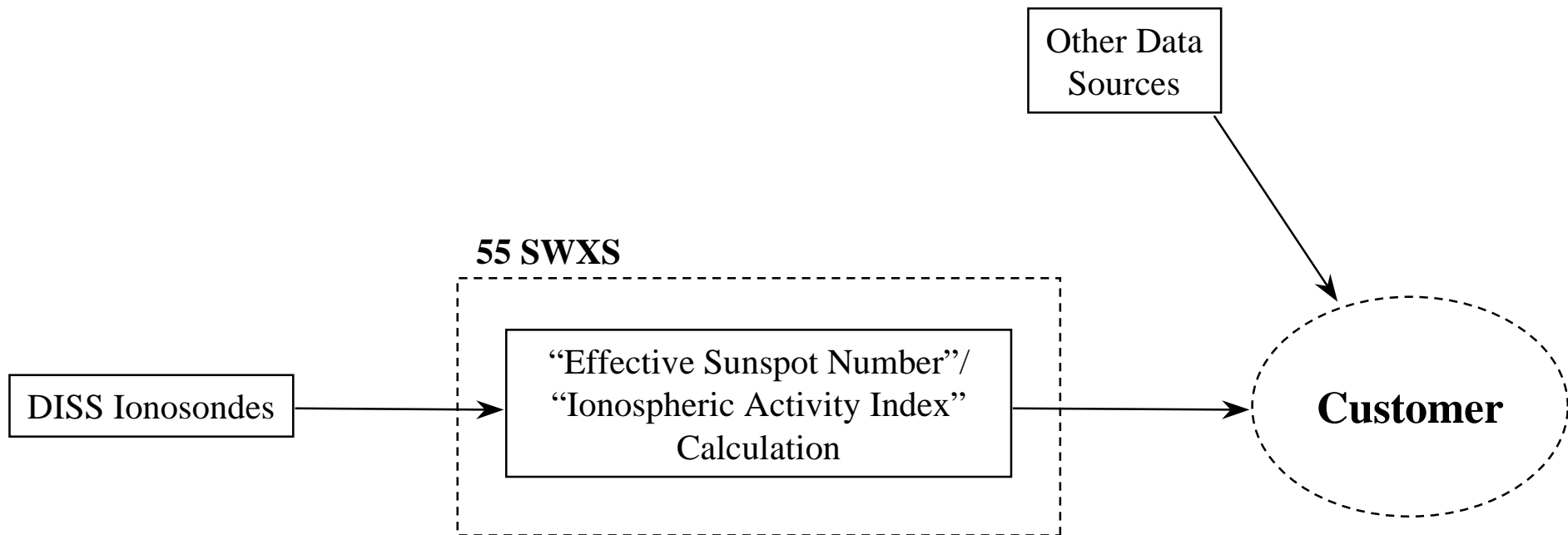
IONOSPHERIC EFFECTS AND SCINTILLATION

- **Use Of JPL TEC Measurements To Assess Single Frequency GPS Errors Currently Underway**
- **CONOPS For Single Frequency GPS Support Via Improved Ionospheric Upload To GPS Satellites Needs Further Investigation To Establish Utility/Viability**
 - » Class II, Medium Impact, but not used to drive NPOESS EDR values
 - » In-situ temperature EDR has lower impact on model than EDPs (Class II, Low Impact)
- **Scintillation Outage Support CONOPS Is Same As For SatCom Except For Inclusion Of GPS Satellite Visibility Analysis at 55SWXS (Class II, High/Medium Impact For Low/High Latitude)**



Current CONOPS for National Programs

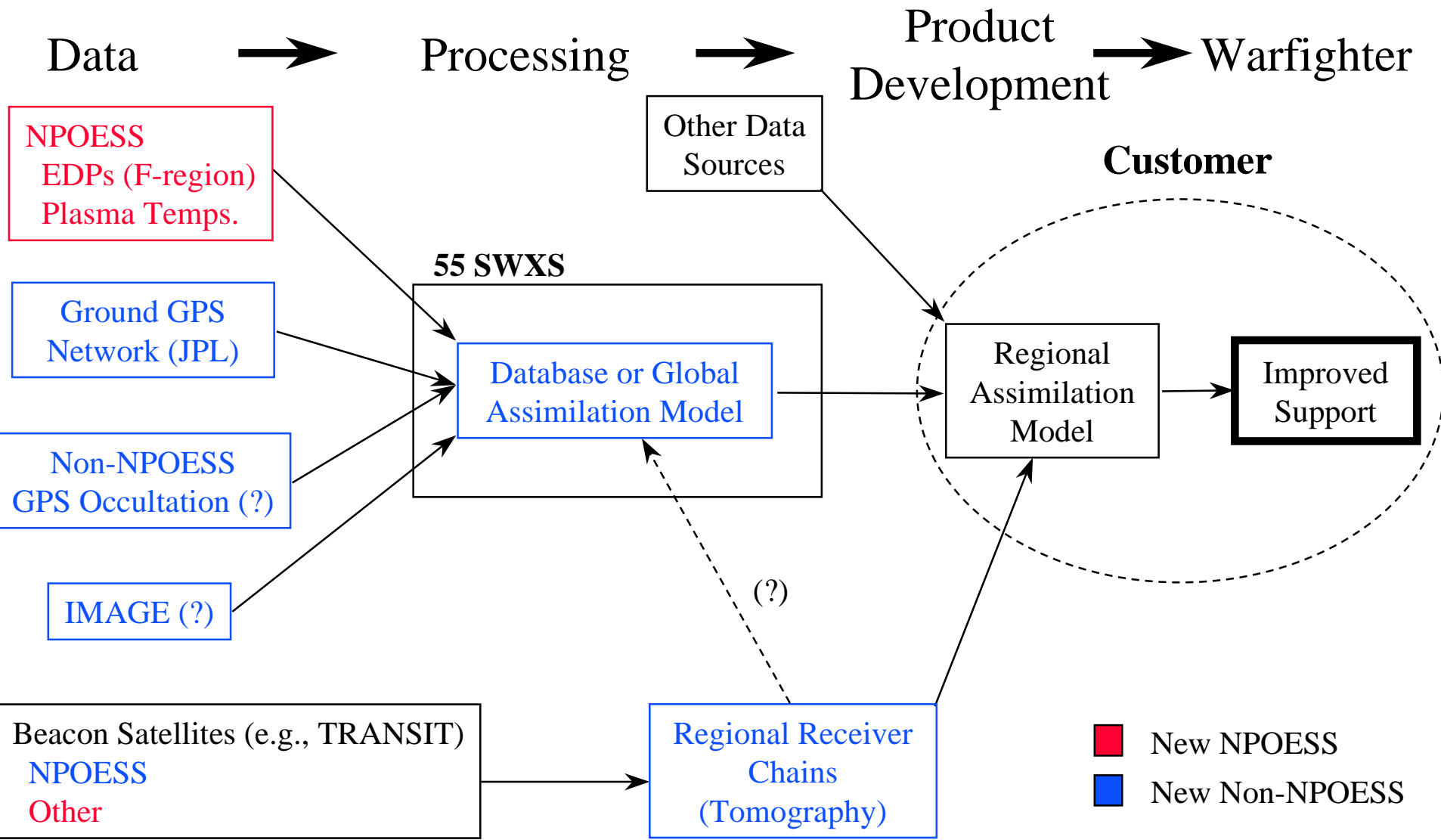
IONOSPHERIC EFFECTS AND SCINTILLATION





Future CONOPS for National Programs

IONOSPHERIC EFFECTS AND SCINTILLATION





Future National Program CONOPS Issues

IONOSPHERIC EFFECTS AND SCINTILLATION

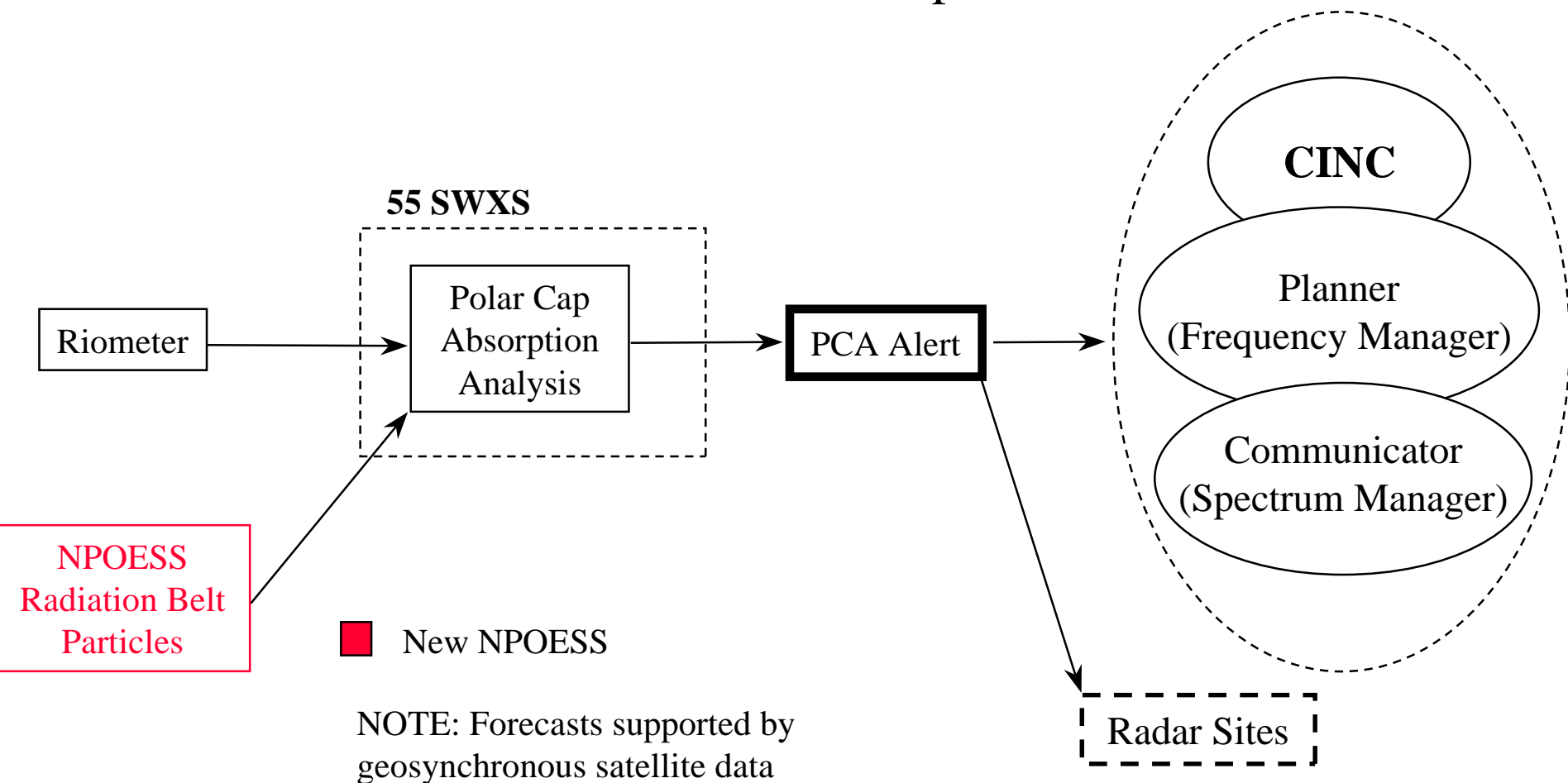
- **NPOESS Can Provide Significant Ionospheric Data, But Probably Can Not Meet Objective End-User Requirements Without Being Augmented By Other Data Sources**
 - » Primarily due to lack of coverage/refresh on a global basis
- **CONOPS Requires Additional Development And Evaluation (Class II, High Impact)**
- **In-Situ Plasma Temperatures May Play Minor Role In Assimilative Model (Class II, Low Impact)**
- **Several Other EDRs Provide For Alternate (Less Likely) First Principles Modeling CONOPS (Class III)**



High Latitude HF Communications Support Current & Future CONOPS

IONOSPHERIC EFFECTS AND SCINTILLATION

Data → Processing → Product Development → Warfighter





High Latitude HF Com Future CONOPS Issues

IONOSPHERIC EFFECTS AND SCINTILLATION

- NPOESS Provides Secondary Data Source Providing Information On State Of Polar Cap (Class I, Low Impact)
- PCA Alert Also Potentially Useful For Some Radar Systems (Class II, Low Impact)



NOAA SEC Space Weather CONOPS

IONOSPHERIC EFFECTS AND SCINTILLATION

Observe Regimes and Parameters

Energetic particles	Plasma environment
Ionosphere	Neutral atmosphere density
Polar cap	Aurora zone
Mid-latitudes	Equatorial latitudes
Solar	Interplanetary
Magnetosphere	

Synthesize
(model)
a
coherent,
current
and future
view of the
space
environment

Produce
specification
alerts
warnings
watches
forecasts
indices
summaries
archives

Disseminate
via
Internet
Web
ftp
e-mail
weather wire
fax
phone
mail

Use
--a decision-making
matrix of actions, information,
costs, and outcomes,
--or tailor information for other users
--or combine SEC guidance along with
space environment information
in a decision process (esp. for NOAA,
other federal agencies)

From individual observations

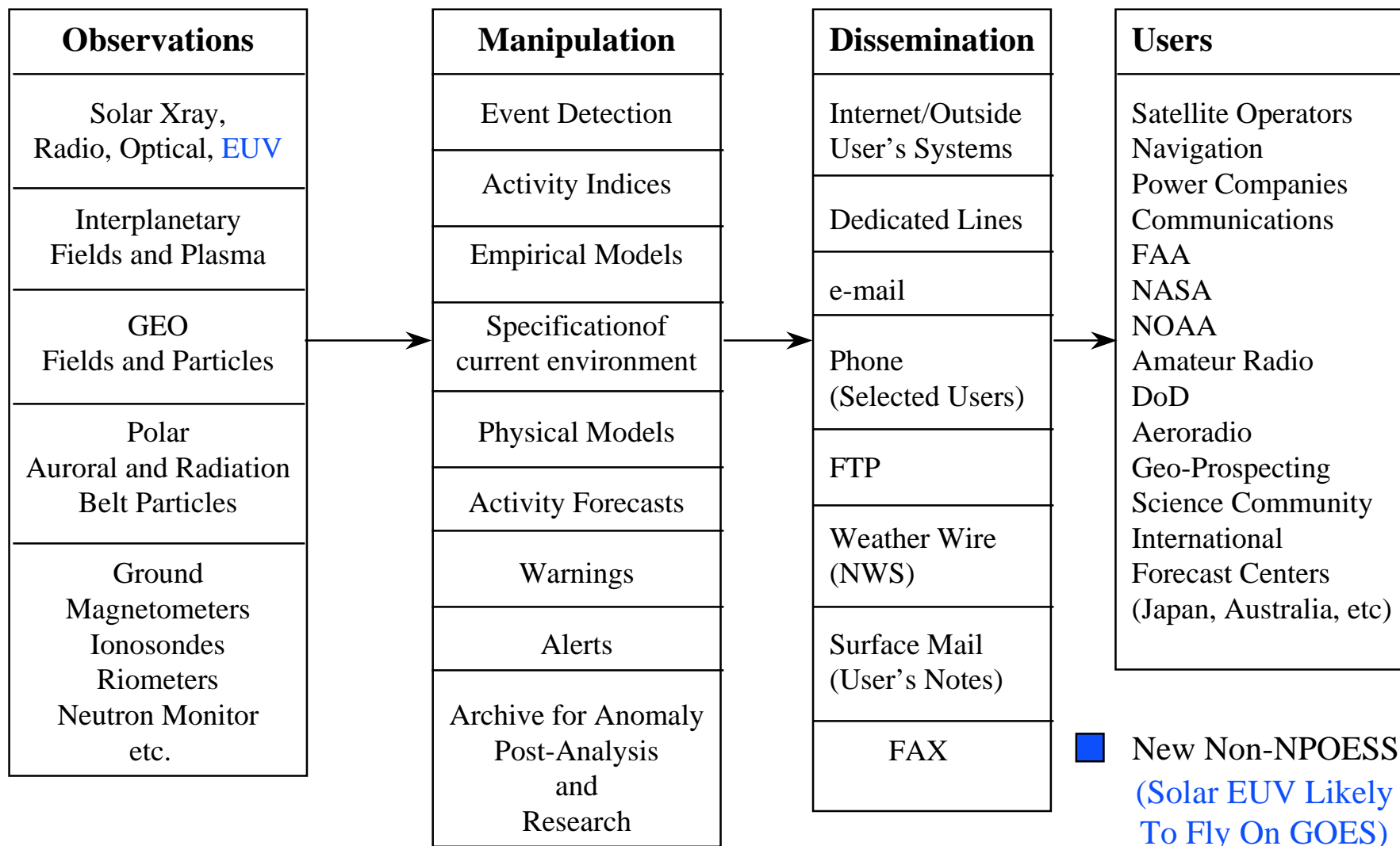
Integrated, coherent information

Decisions



Current & Future DOC Situational Awareness CONOPS

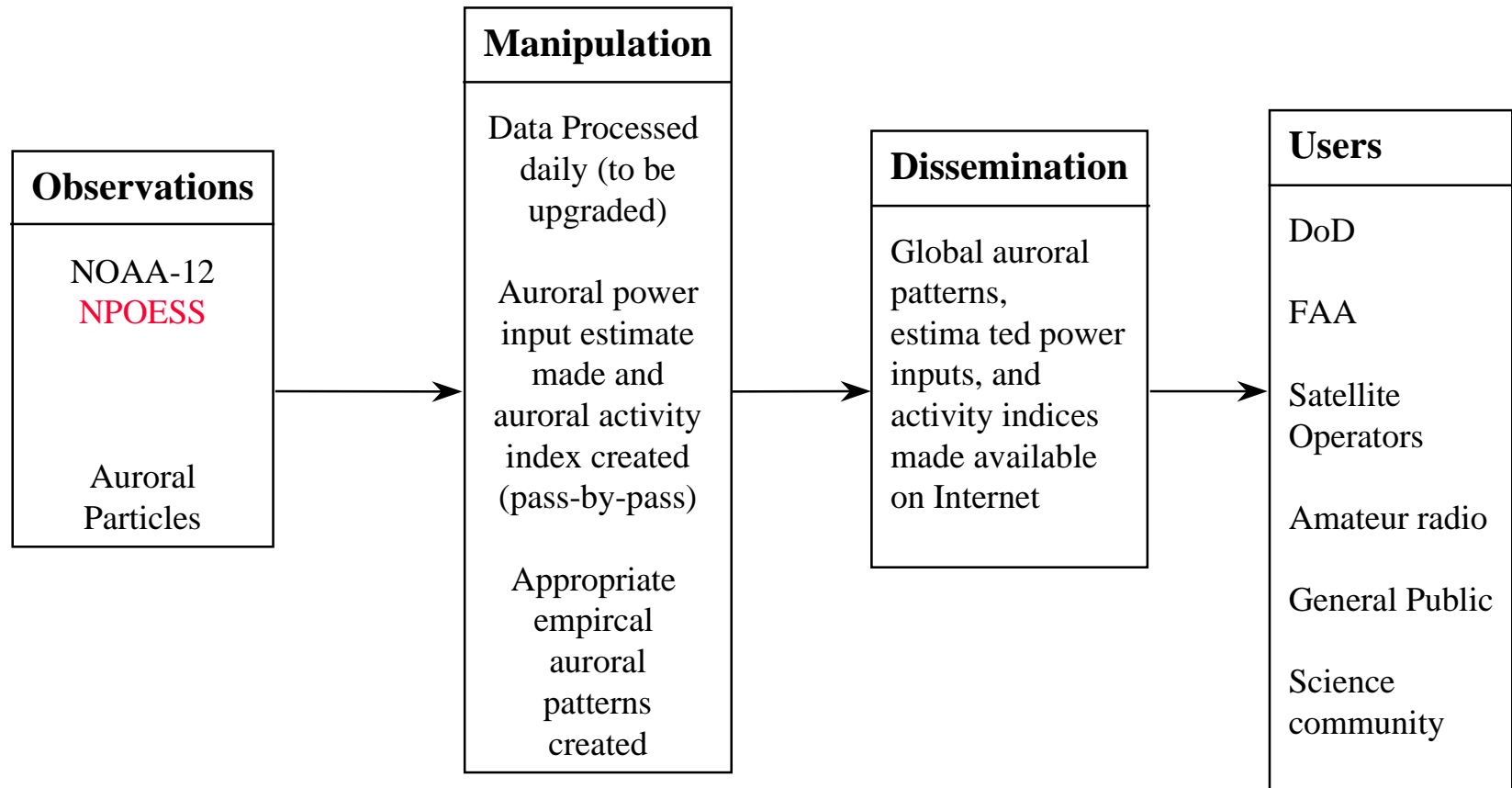
IONOSPHERIC EFFECTS AND SCINTILLATION





Current & Future DOC Auroral Oval Characterization CONOPS

IONOSPHERIC EFFECTS AND SCINTILLATION





Comments on DOC CONOPS

IONOSPHERIC EFFECTS AND SCINTILLATION

- DOC SES Charter Requires Acquisition of Data to Keep Civilian Community Aware of Space Environment Conditions and Disturbances, but Precludes Direct Solutions of User Problems
 - » 3rd party vendor using DOC data preferred
- DOC CONOPS Requires a Few Primary EDRs
 - » Auroral Boundary & Energy Deposition, Solar EUV, Electric Fields, Radiation Belt Particles
- DOC Will Make Use of Other EDRs Driven by DOD
- All Primary EDRs in DOC CONOPS Ranked as Class I (Varying Impacts)



Summary of NPOESS Contributions I

IONOSPHERIC EFFECTS AND SCINTILLATION

- **Primary Importance**
 - » Auroral Boundary & Imagery for Radar Clutter Assessment
 - » Auroral Boundary, Energy Deposition, Electric Field, & Solar EUV (if not on GOES) for DOC Situational Awareness
 - » Electron Density Profiles for National Programs and scintillation induced SatCom/GPS outage predictions
 - » High & low latitude Electric Fields and In-Situ Fluctuations, also for scintillation impacts



Summary of NPOESS Contributions II

IONOSPHERIC EFFECTS AND SCINTILLATION

- **Secondary Importance**
 - » Electron Density Profiles for validation of Radar range correction models and high latitude scintillation/clutter support
 - » Electron Density Profiles for improved corrections to single frequency GPS
 - » Scintillation observations (other sources of this type of data exist and the NPOESS polar orbit is not optimal)
 - » Radiation Belt Particles for polar cap absorption alerts
 - » Plasma temperatures for National Programs/GPS Single Frequency support



Briefing Outline

IONOSPHERIC EFFECTS AND SCINTILLATION

Task 2 Objectives

User Areas & Requirements Assessed

Concepts of Operation

→ EDR Prioritization

EDR Changes



Ionospheric Group EDR Prioritization

IONOSPHERIC EFFECTS AND SCINTILLATION

EDRs	Ranking	Utility Level/Mission Impact						Notes
		Classified	Comm/Nav		Radar	DOC		
			Low Lat	High Lat	Single Fr GPS			
Auroral Boundary	1	III		I/High		I/High	I/High	
Electric Field	2	III	II/High	II/Med		II/Med	I/High	
Auroral Energy Deposition	3						I/High	
						II/Med		Three aspects to radar support: (1) E for clutter; (2) F-region/auroral for s profiles/everywhere for ionosphere c
Electron Density Pro	4	II/High	II/High	II/Med	II/Med	II/Med	III	
Solar EUV	5	III				I/Low	I/Med	
Auroral Imagery	6						III	
In-Situ Fluctuations	7		II/High	II/Med		I/Med	III	
Radiation Belt	8			I/Low		II/Med	III	
Te, Ti	9	II/Low			I/Low	II/Low	I/Low	Backup for ground based riometer
Scintillation	10		III	III			III	
Precipitating Particles	11	III		III		II/Low	III	
Neutral Density Profiles	12	III				III	III	
UV Airglow	Class IV							Derived EDR
Magnetic Field	Class V							
Cosmic Rays	Class V							
In-Situ Drift Velocity	N/A							Merged with Electric Field
In-Situ Plasma Density	N/A							Merged with Electron Density Profil
Neutral Winds	New EDR	III	II/High				III	



Briefing Outline

IONOSPHERIC EFFECTS AND SCINTILLATION

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→ EDR Changes



Auroral Boundary

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Accuracy	50 (10) km <i>100</i> (10) km	IORD-1 <i>Recommended</i>
----------	----------------------------------	------------------------------

Justification:

- Regions that produce auroral clutter for military radar systems are a few hundred km in size. To help assess the presence of clutter, the auroral boundary location must be known to at least 100 km accuracy.



Auroral Energy Deposition

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Meas. Range

Electrons	10^{-4} to 1.0 (5×10^{-5} to 1.0) W/m ²	IORD-1
Ions	10^{-4} to 10^{-1} (5×10^{-5} to 10^{-1}) W/m ²	IORD-1
Accuracy	$\pm 20\%$ or $\pm 10^{-4}$ ($\pm 10\%$ or $\pm 5 \times 10^{-5}$) W/m ²	IORD-1

Justification:

- Name changed from “Total Auroral Energy Deposition”. The term “total” is misleading since it can be interpreted as requiring NPOESS to provide a global measurement of this quantity. Ground processing algorithms which convert a local or regional measurement of auroral energy deposition into an estimate of the global average energy deposition are not considered by DOC to be part of NPOESS contractor responsibility.



Auroral Imagery

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Meas. Range	120 to 180 (80 to 250) nm	IORD-1
	<i>Determine auroral features 75 (100)% of time</i>	<i>Recommended</i>
Accuracy	± 10 (5)%	IORD-1
	<i>Determine auroral features 75 (100)% of time</i>	<i>Recommended</i>
Horiz. Resolution	20 (10) km	IORD-1
	<i>100 (10) km</i>	<i>Recommended</i>

Justification:

- Specific wavelength range for Measurement Range represents a particular sensor. Intensities are dependent on the auroral emissions to be measured. It should be left up to the contractor to recommend a particular sensor solution in these areas. Statistical models of auroral emissions can be used by the contractor to determine Measurement Range and associated Accuracies.
- Statistically dimmer auroral features can be ignored as a threshold since they have lower impact on radar systems.
- Regions that produce auroral clutter for military radar systems are a few hundred km in size. To help assess the presence of clutter, the region locations must be known to at least 100 km accuracy.



Electric Field

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Meas. Range	0 to 150 (0 to 250) mV/m		IORD-1
	<i>±150 (250) mV/m</i>		<i>Recommended</i>
Meas. Precision	2 mV/m	0.1 mV/m	IORD-1
Meas. Accuracy	±3 mV/m	±0.1 mV/m	IORD-1
<i>Meas. Uncertainty</i>	<i>±3 mV/m</i>	<i>0.1 mV/m</i>	<i>Recommended</i>
<i>(Meas. Uncertainty replaces Precision & Accuracy)</i>			

Justification:

- Electric Field is a signed observable.
- No reason to specify separate Accuracy and Precision. Total Uncertainty is correct measure of merit.
- Note: Meas. Ranges and threshold Uncertainty are associated with auroral zones while objective Uncertainty is associated with low latitude regions.



Electron Density Profiles

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Horiz. Resolution		
0° to 30° Lat	200 (100) km	IORD-1
	<i>100 (10) km</i>	<i>Recommended</i>
30° to 50° Lat	500 (250) km	IORD-1
50° to 90° Lat	100 (50) km	IORD-1
	<i>50 (10) km</i>	<i>Recommended</i>
Vert. Resolution		
Within 100 km of E- or F-layer peaks	10 (5) km	IORD-1
Elsewhere	20 (5) km	IORD-1

Justification:

- Name changed from “Electron Density Profiles/Ionospheric Specification” because Ionospheric Specification is misleading. NPOESS is not responsible for the development of a specification model, although NPOESS data might be used in such a model.
- Finer horizontal resolution is required in the low and high latitudes to support concepts of operation associated with scintillation prediction. Thresholds are derived from typical mesoscale size ionospheric features, while objectives support characterization of sharp transitional regions (plasma “blob” and depletion boundaries).



Electron Density Profiles (cont.)

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Meas. Range

Local density	3×10^5 to 10^7 (10^4 to 10^7 cm ⁻³) cm ⁻³	IORD-1
	<i>N/A</i> (10^4 to 10^7) cm ⁻³	<i>Recommended</i>
TEC	3×10^{16} to 2×10^{18} (10^{16} to 2×10^{18}) m ⁻²	IORD-1
foF2	5 to 30 (1 to 30) MHz	IORD-1
	<i>(delete foF2 Meas. Range)</i>	<i>Recommended</i>

Justification:

- The existing CONOPS do not drive specification of local density (i.e., the density at an arbitrary altitude on the measured profile) as a threshold parameter.
- foF2 is a redundant specification with NmF2 or local density, and is tied to HF communications CONOPS, which are not considered requirements drivers at present.



Electron Density Profiles (cont.)

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Meas. Accuracy		
Local density	$\pm 3 \times 10^5 (\pm 10^4) \text{ cm}^{-3}$	IORD-1
	<i>N/A ($\pm 10^4$) cm^{-3}</i>	<i>Recommended</i>
NmF2	$\pm 20 (5)\%$	IORD-1
NmF2 (<i>low/high lat</i>)	$\pm 20 (\pm 10)\%$	<i>Recommended</i>
HmF2	$\pm 20 (\pm 5) \text{ km}$	IORD-1
HmF2 (<i>low lat</i>)	<i>$\pm 25 (\pm 10) \text{ km}$</i>	<i>Recommended</i>
<i>In-Situ Ion Composition</i>	<i>N/A (5% of total density)</i>	<i>Recommended</i>

Justification:

- The existing CONOPS do not drive specification of local density as a threshold parameter. It should be left up to the contractor to determine what profile accuracies are required to meet the other thresholds (NmF2, HmF2, NmE, TEC).
- NmF2 and HmF2 are required to support scintillation prediction CONOPS at low and high latitudes. Thresholds and objectives are related to the ability to predict scintillation induced fades to levels which are operationally relevant.
- In-Situ Ion Composition is added as an objective carried over from the merged In-Situ Plasma Density EDR. Ion composition data is a potentially useful input for an assimilative model.



Electron Density Profiles (cont.)

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Meas. Accuracy (cont.)

TEC	max[$\pm 20\%$, $3 \times 10^{16} \text{ m}^{-2}$] ($\pm 10^{16}$) m^{-2}	IORD-1
	max[<i>$\pm 30\%$</i> , $3 \times 10^{16} \text{ m}^{-2}$] ($\pm 10^{16}$) m^{-2}	<i>Recommended</i>
<i>Bottomside vertical</i>	<i>20 (10) km</i>	<i>Recommended</i>
<i>gradient scale length</i>		
<i>(low lat)</i>		
<i>NmE (highlat)</i>	<i>20 (5)%</i>	<i>Recommended</i>

Justification:

- National Programs CONOPS requires threshold TEC accuracy to significantly exceed existing climatology (60%). This implies some relaxation of the threshold value. While National Program and Radar systems actually require arbitrary slant path profiles, it is not reasonable to expect that NPOESS measure this. However, specifying the accuracy of the vertically integrated that NPOESS profiles (TEC) at this level insures that the NPOESS data would be useful in an assimilation model (National Programs) or as a model calibration (Radars). *Text should be added to the EDR description to explain this.*
- Bottomside gradient is a key parameter needed to support low latitude scintillation predictions.
- NmE is a key parameter needed to support high latitude radar systems clutter evaluations



In-Situ Ion Drift Velocity

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Recommend Combining with Electric Field EDR

Justification:

- This EDR is redundant with the Electric Field EDR, which is the more fundamental requirement.



In-Situ Plasma Density

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Recommend Combining with Electron Density Profile and In-Situ Fluctuations EDRs

Justification:

- In-situ density is redundant with Electron Density Profile EDR, as used in all CONOPS if full profiles are measured. Only remaining aspect is Ion Composition, which is specified in IORD text for In-Situ Plasma Density but not in the EDR attributes. Recommend that Ion Composition be added to Electron Density Profiles as an objective.
- Scintillation support using In-Situ Fluctuation measurements requires both absolute and relative fluctuation observations, implying a need to know the mean in-situ plasma density. It is therefore appropriate to merge In-Situ Plasma Density/Fluctuations.



In-Situ Plasma Fluctuations

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

In-Track Resolution	100 km (5 m) <i>200 km (100 km)</i>	IORD-1 <i>Recommendation</i>
Meas. Range		
Spectral Index	2 to 5 (1 to 10) <i>1 to 5</i>	IORD-1 <i>Recommendation</i>
$\Delta n/n$	10^{-2} to 1.0 (10^{-4} to 1.0) <i>10^{-2} to 1.0</i>	IORD-1 <i>Recommendation</i>
<i>Accuracy</i>		
<i>Mean Density</i>	<i>20 (5)%</i>	<i>Recommendation</i>

Justification:

- Resolution threshold can be relaxed to match minimal size of scintillating regions. 5 m objective is an error related to the actual sample rate associated with determining the spectral index and $\Delta n/n$. The reported quantities are not needed at this resolution.
- Spectral indices above 5 do not occur in nature.
- Low level fluctuations do not result in scintillation impacts on operational systems.
- Absolute in-situ fluctuation levels (the same as knowing the mean density) are required to allow accurate estimation of L- and S-band scintillation levels in equatorial and polar regions.



Ionospheric Scintillation

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Horiz. Resolution	100 (50) km	IORD-1
Meas. Range		
Amplitude Index (S4)	0.1 to 1.5	IORD-1
Phase Index (sigma-phi)	0.1 to 20 radians	IORD-1
Meas. Precision		IORD-1
<i>Meas. Uncertainty (replaces Precision)</i>		<i>Recommendation</i>
Amplitude Index (S4)	0.1	IORD-1
Phase Index (sigma-phi)	0.1 radians	IORD-1
Meas. Accuracy	factor of ± 2	IORD-1
<i>(Delete Meas. Accuracy)</i>		<i>Recommendation</i>

Add Specification of applicable frequency bands (S-band, L-band, and UHF) to the text describing this EDR

Justification:

- Frequency bands of interest must be specified to provide a complete specification of this EDR
- Uncertainty, not precision, is the requirement for scintillation measurements
- Measurement accuracy should be deleted in favor of measurement uncertainty. The factor of 2 specification is a hold over from an early version of the document which specified different parameters than S4 and sigma-phi. It is no longer applicable.



Solar EUV Flux

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Meas. Range	5 to 130 (1 to 175) nm	IORD-1
	4 (10) channels	IORD-1
	<i>5 (13) channels</i>	<i>Reommended</i>
Meas. Accuracy	$\max[\pm 10^{-4} (\pm 5 \times 10^{-5}) \text{ W/m}^2, \pm 20 (\pm 10)\%]$	IORD-1

Justification:

- Consistency with GOES sensor for threshold and with latest SEC study for objective.



Upper Atmospheric Airglow

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Recommend Deleting This EDR Since It Is Derived From The Electron And Neutral Density Profile EDRs. If Kept, The Following Changes Should Be Made.

In Track Resolution (Limb)	750 (100) km	IORD-1
Horiz. Resolution (Disk)		
0° to 30° Lat	200 (100) km	IORD-1
	<i>100 (10) km</i>	<i>Recommended</i>
30° to 50° Lat	500 (250) km	IORD-1
50° to 90° Lat	100 (10) km	IORD-1
	<i>50 (10) km</i>	<i>Recommended</i>
Vert. Resolution (Limb)	20 (5) km	IORD-1

Justification:

- Consistency with Electron Density Profile EDR requirements



Upper Atmospheric Airglow (cont.)

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

Meas. Range		
Limb, at 83.4 nm	20 to 1000 (10 to 1000) R	IORD-1
	20 to <i>3000</i> (10 to <i>5000</i>) R	<i>Recommended</i>
Limb, at 135.6 nm	0.2 to 10 (0.1 to 10) kR	IORD-1
	<i>0.02</i> to 10 (<i>0.5 to 20</i>) kR	<i>Recommended</i>
Limb, at 140 to 180 nm	0.2 to 30 (0.1 to 30) kR	IORD-1
Disk, at 121.6 nm	1 to 30 (0.5 to 30) kR	IORD-1
	1 to <i>10</i> (0.5 to 30) kR	<i>Recommended</i>
Disk, at 135.6 nm	4 to 4000 (1 to 4000) R	IORD-1
	<i>5 to 3000 (0.5 to 6000) R</i>	<i>Recommended</i>
Disk, at 140 to 180 nm	4 to 5000 (1 to 5000) R	IORD-1
	<i>10 to 3000 (5 to 6000) R</i>	<i>Recommended</i>
Meas. Accuracy	±10 (5)%	IORD-1

Justification:

- NRL review of anticipated range of airglow brightnesses consistent with Electron and Neutral Density Profile EDRs.



Neutral Winds

(Changes in *Red Italics*)

IONOSPHERIC EFFECTS AND SCINTILLATION

<i>Horiz. Rep. Interval</i>	<i>200 (10) km</i>	<i>Recommended</i>
<i>Horiz. Coverage</i>	<i>± 30 deg magnetic (global)</i>	<i>Recommended</i>
<i>Meas. Range</i>	<i>± 300 (500) m/s</i>	<i>Recommended</i>
<i>Meas. Uncertainty</i>	<i>20 (5) m/s</i>	<i>Recommended</i>

Justification:

- Neutral winds are a determining factor in the generation of equatorial scintillation.



ORBITAL DRAG - ATMOSPHERIC DENSITY

Task 2 - EDR Assessment & Validation

Orbital Drag - Atmospheric Density Working Group

Members

Diane Buell, IPO

Frank Marcos, AFRL

Mike Picone, NRL

Tim Fuller-Rowell, NOAA/SEC

Richard Walterscheid, Aerospace

Mark Storz, AFSC/SWC

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BRIEFING OUTLINE

ORBITAL DRAG - ATMOSPHERIC DENSITY



BACKGROUND

- Task 2 Objectives
- Applications
- Requirement
- Baseline Performance
- Space Environment Support

CONOPS

NPOESS EDRs

PRIORITIZATION

SUMMARY



BACKGROUND

Task 2 Objectives

ORBITAL DRAG - ATMOSPHERIC DENSITY

Task 2 Objectives

- **Document existing CONOPS (data, models, methods)**
- **Identify future CONOPS**
- **Determine contributions from NPOESS**
- **Prioritize NPOESS EDRs**



BACKGROUND

Applications

ORBITAL DRAG - ATMOSPHERIC DENSITY

- **End users**
 - » **CMOC Space Control Center**
 - » **NASA Marshall Space Flight Center**
 - » **Naval Space Command**
- **Applications**
 - » **Precision ephemerides**
 - **DMSP**
 - **Special interest satellites**
 - » **Collision avoidance**
 - **Space shuttle**
 - **Space station**
 - » **Re-entry prediction**



BACKGROUND

Requirement

ORBITAL DRAG - ATMOSPHERIC DENSITY

- **Study re-validated 1988 US Space Command requirement:**
 - » **Altitudes**
 - 90 - 800 (1500) km
 - » **Average * neutral density error**
 - under 500 km 10 (5)%
 - 500 - 700 km 15 (10)%
 - over 700 km 20 (15)%
 - » **Prediction**
 - 24 - 72 hours, updated every 24 hours
 - » **Coverage**
 - All latitudes and longitudes

values in () are objective requirements

** interpreted as orbit-averaged*



BACKGROUND

Baseline Performance

ORBITAL DRAG - ATMOSPHERIC DENSITY

- **Current neutral density models provide ~15% accuracy (point-to-point comparison)**
- **NPOESS funded an IGS to determine average neutral density error (orbit-averaged)**
 - » **For data studied, results show averaged standard deviations are 2 - 3.5% less than the point values**
- **Today's systems and models are not meeting validated neutral density accuracy requirements**



BACKGROUND

Space Environment Support

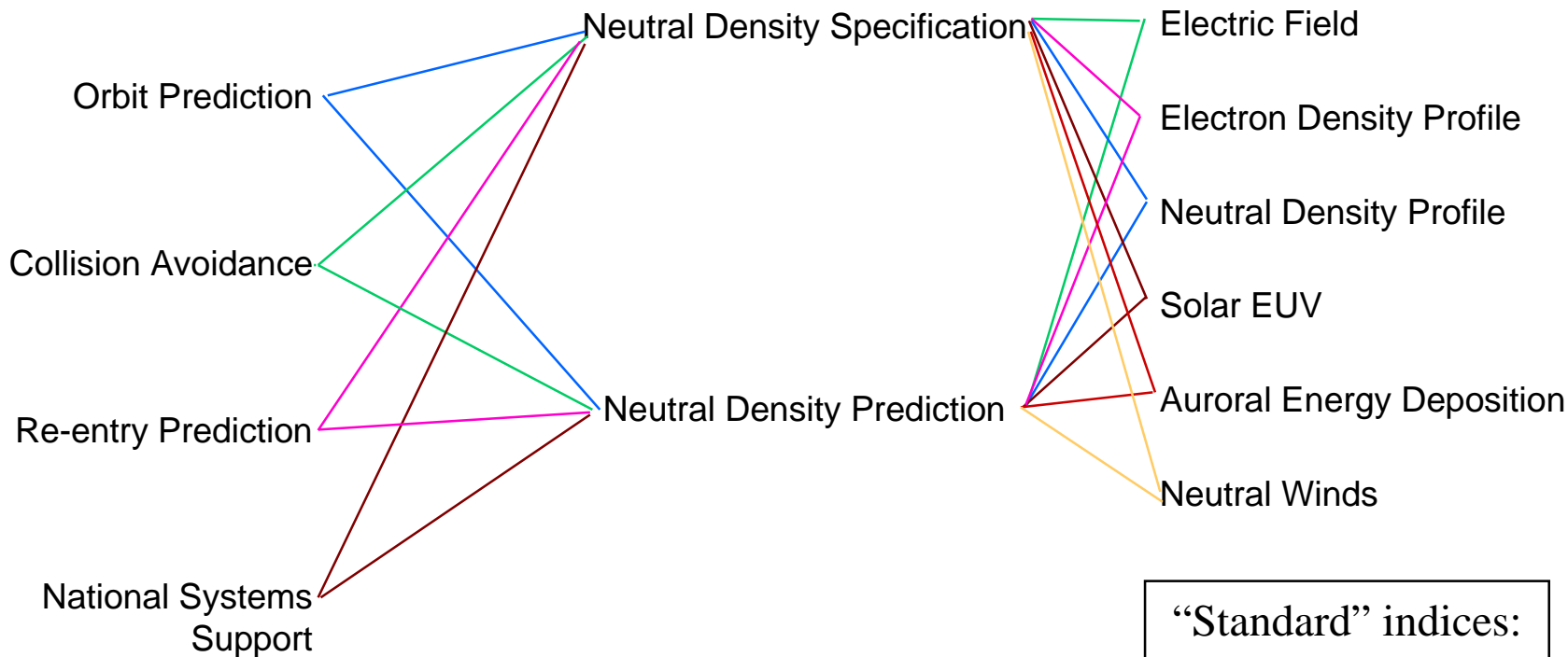
ORBITAL DRAG - ATMOSPHERIC DENSITY

Space Environment Support

Mission

Needs

EDRs



“Standard” indices:
F10.7, Ap



BRIEFING OUTLINE

ORBITAL DRAG - ATMOSPHERIC DENSITY



BACKGROUND CONOPS

- Current
- Near-term
- Future

• NPOESS EDRs PRIORITIZATION SUMMARY



CONCEPT OF OPERATIONS

Status (Current, Near-term, Future)

ORBITAL DRAG - ATMOSPHERIC DENSITY

Atmospheric Density in support of Orbital Drag

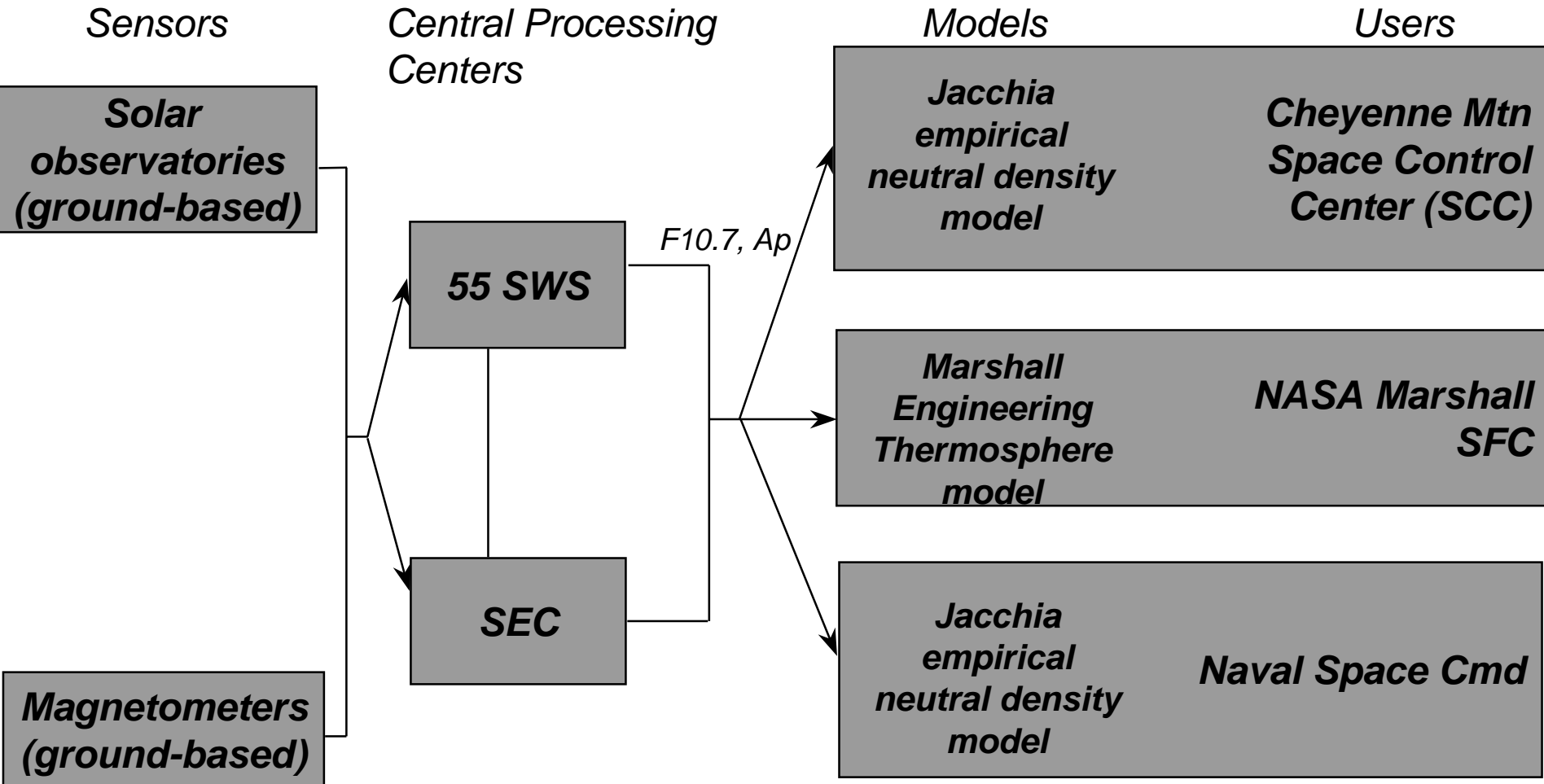
- **Current:** ground-based sensors providing proxy values to empirical density models
- **Near-term:** use of space surveillance tracking data to enhance density prediction
- **Future - threshold:**
 - **Assimilative process** relying on space-based sensing to enhance empirical models
- **Future - objective:**
 - **Assimilative process and first-principles models** relying on space-based sensing to enhance empirical models



CONCEPT OF OPERATIONS

Current

ORBITAL DRAG - ATMOSPHERIC DENSITY

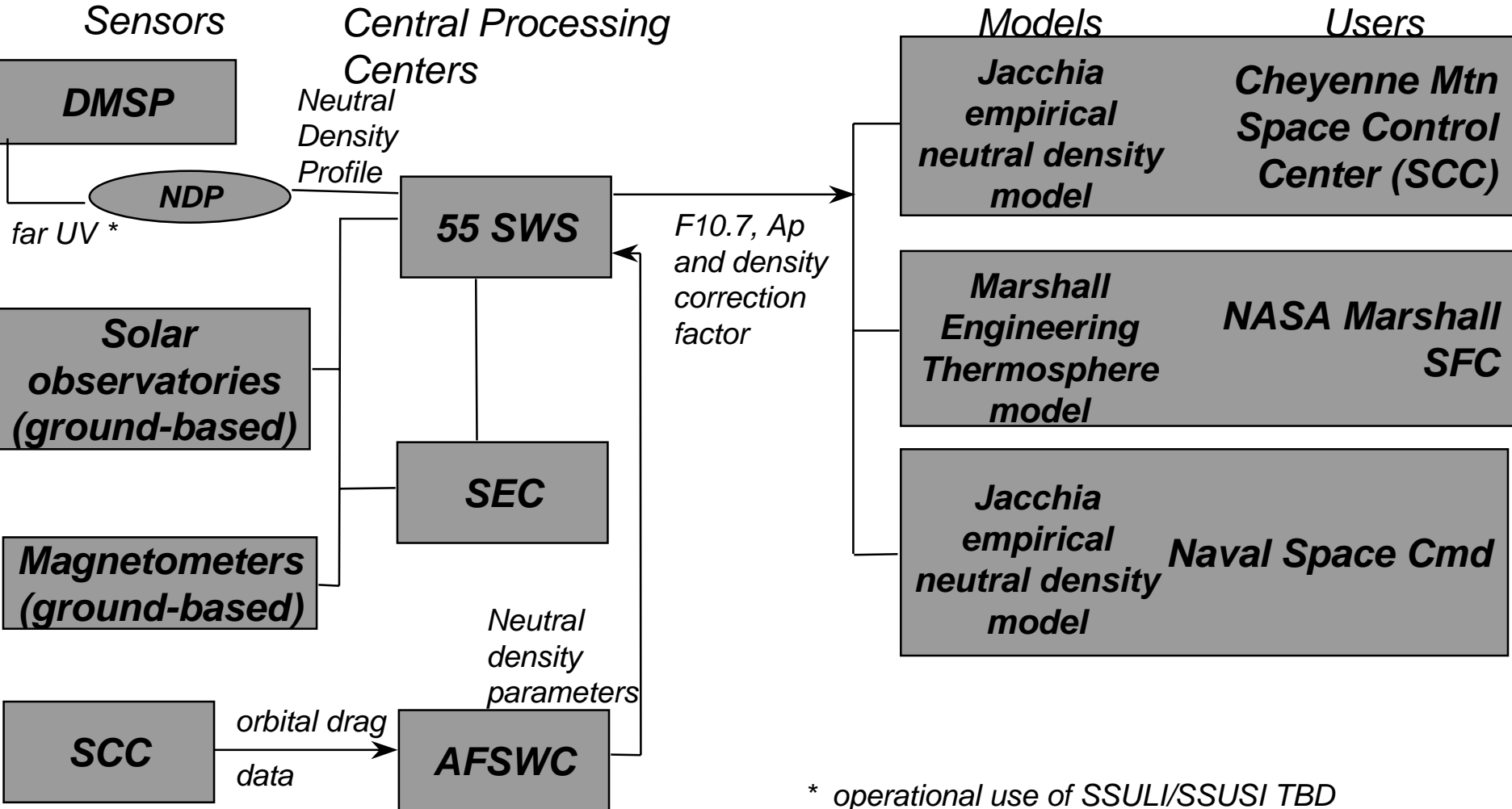




CONCEPT OF OPERATIONS

Near-term

ORBITAL DRAG - ATMOSPHERIC DENSITY

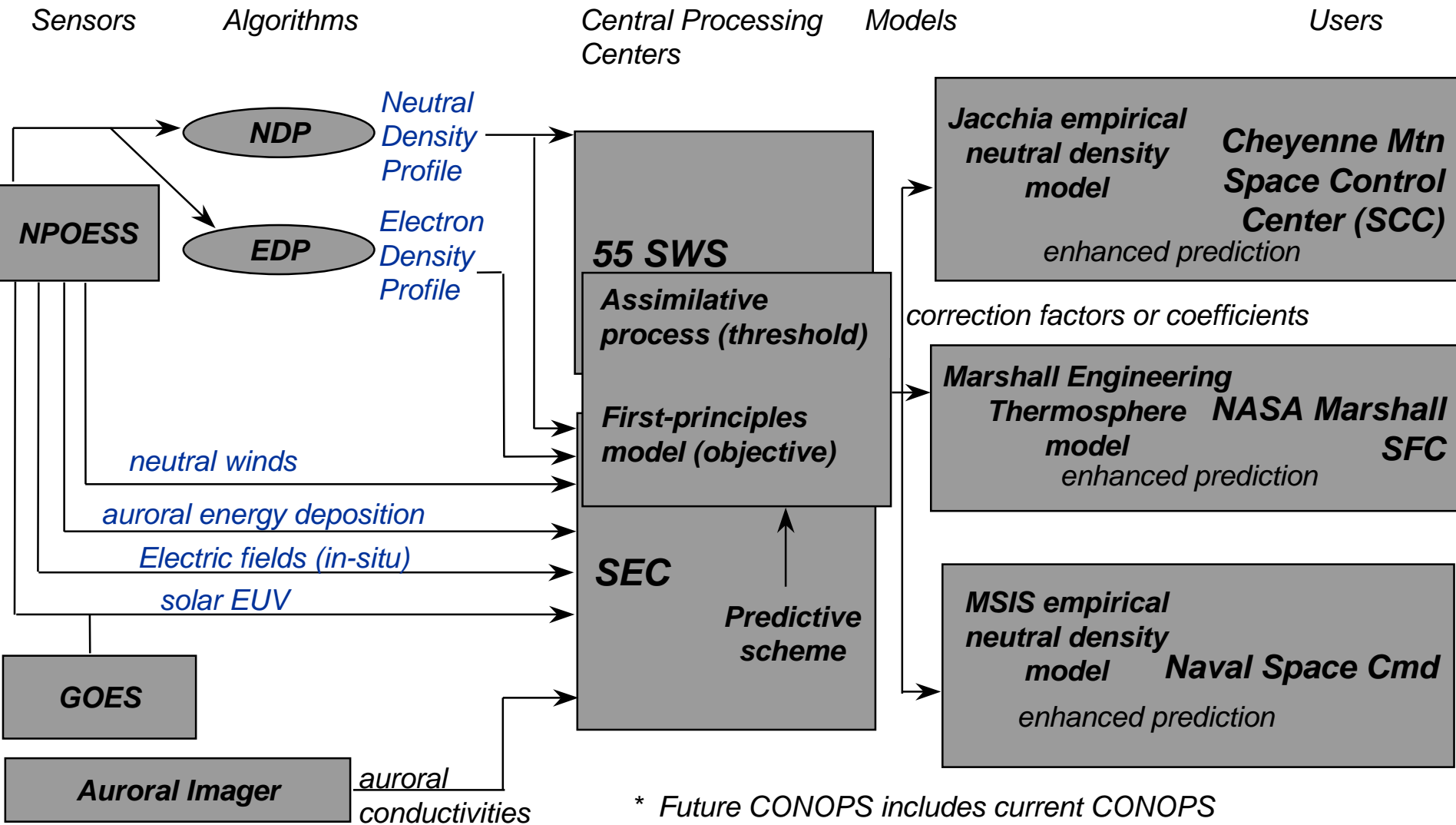




CONCEPT OF OPERATIONS

Future *

ORBITAL DRAG - ATMOSPHERIC DENSITY



* Future CONOPS includes current CONOPS



CONCEPT OF OPERATIONS

Issue

ORBITAL DRAG - ATMOSPHERIC DENSITY

Atmospheric Density in support of Orbital Drag

- **Validation and operational utility and benefit of SSUSI and SSULI**
 - **This determines the feasibility of future threshold concept of operations**



BRIEFING OUTLINE

ORBITAL DRAG - ATMOSPHERIC DENSITY

BACKGROUND CONOPS



NPOESS EDRs

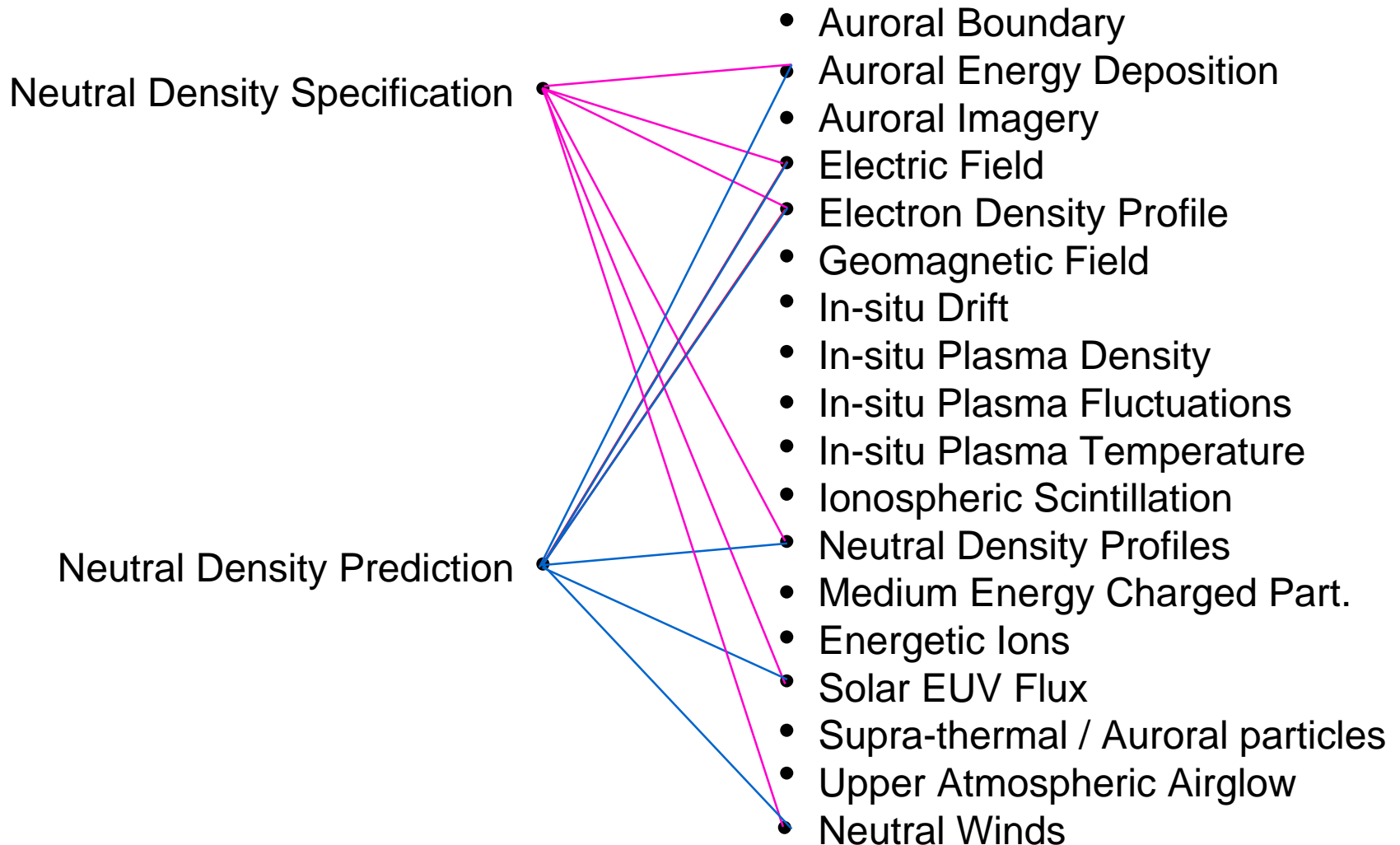
- Effect to NPOESS EDRs
- Assigned EDRs and status
- IORD-1 versus Assigned EDRs

PRIORITIZATION SUMMARY



Need-to-NPOESS EDR Mapping

ORBITAL DRAG - ATMOSPHERIC DENSITY





Atmospheric Density for Orbital Drag

(Affected EDRs in red italics)

ORBITAL DRAG - ATMOSPHERIC DENSITY

SES EDRs	Relevancy	WG Comments
Auroral Boundary		
Auroral Energy Deposition	<i>Moderate</i>	<i>First-principles model input</i>
Auroral Imagery		
Electric Field	Moderate	First-principles model input
<i>Electron Density Profile</i>	<i>Moderate</i>	<i>First-principles model input</i>
Geomagnetic Field		
In-situ Drift		Redundant - see E-field
In-situ Plasma Density		
In-situ Plasma Fluctuations		
In-situ Plasma Temperature		
Ionospheric Scintillation		
<i>Neutral Density Profiles</i>	<i>High</i>	<i>Primary EDR</i>
Medium Energy Charged Part.		
Energetic Ions		
<i>Solar EUV Flux</i>	<i>Moderate</i>	<i>Assimilative process input</i>
Supra-thermal/Auroral Part.		
Upper Atmospheric Airglow		Sensor solution for nd profile
<i>Neutral Winds</i>	<i>Low</i>	<i>Drag correction</i>



IORD-1 EDR Changes

(Changes indicated in *Red Italics*)

ORBITAL DRAG - ATMOSPHERIC DENSITY

Auroral Energy Deposition

Measurement Range	e ⁻	10 ⁻⁴ (5x10 ⁻⁵) to 1.0 W/m ²	IORD-1
	p ⁺	10 ⁻⁴ (5x10 ⁻⁵) to 10 ⁻¹ W/m ²	IORD-1
<i>Energy flux</i>		<i>10⁻⁴ (5x10⁻⁵) to 1.0 W/m²</i>	Recommendation
<i>Mean energy</i>		<i>100 eV - 20 keV (30 eV - 30 keV)</i>	Recommendation
Measurement Accuracy ¹		±20% / ±10 ⁻⁴ W/m ² ±10% / ±5x10 ⁻⁵ W/m ²	IORD-1
		<i>10 (5) %</i>	Recommendation

Justification:

- To satisfy requirements for Joule and particle heating for first-principles models, “maps” of energy deposition need to be specified (total column deposition and characteristic energy).

¹Greater of



IORD-1 EDR Changes

(Changes indicated in *Red Italics*)

ORBITAL DRAG - ATMOSPHERIC DENSITY

Electron Density Profile

HORIZ. RESOLUTION	0-30 lat: 200 (100) km; 30-50 lat: 500 (250) km; 50-90 lat: 100 (50) km <i>In-track: 50-90 lat: 100 (50) km</i>	IORD-1 Recommendation
VERTICAL RESOLUTION	w/in 100 km of E/F layer peak: 10 (5) km; elsewhere: 20 (5) km <i>90-150 km: 5 (3) km; 150-500 km: 10 km</i>	IORD-1 Recommendation
RANGE	3×10^5 to 10^7 cm ⁻³ (10^4 to 10^7 cm ⁻³)*	IORD-1
ACCURACY	3×10^5 cm ⁻³ (10^4 cm ⁻³) <i>10 (5)%</i>	IORD-1 Recommendation

Justification:

- The resolution requirements are derived from the ability to perform first-principles simulations of the response to relevant energy sources globally.
- * see notes page.



IORD-1 EDR Changes

(Changes indicated in *Red Italics*)

ORBITAL DRAG - ATMOSPHERIC DENSITY

Neutral Density Profile Map

SENSING DEPTH	100 (90) to 750 (1600) km <i>90 - 800 (1600) km</i>	IORD-1 Recommendation
HORIZ. RESOLUTION	In-track: 500 (50) km <i>In-track: 500 (250) km Cross-track: 2500 (1250) km</i>	IORD-1 Recommendation
VERTICAL RESOLUTION	up to 120 km: 10 (0.5) km; above 120 km: 10 (3) km <i>90-120 km: 5 (0.5) km; >120 km: 5 (3) km</i>	IORD-1 Recommendation
RANGE	3×10^{-9} to 2×10^{-19} g/cm ⁻³ <i>3×10^{-9} to 2×10^{-19} g/cm³</i>	IORD-1 Recommendation
ACCURACY	100 (90) - 500 km: 15 (5)%; 500 - 700 km: 20 (10) % 700 - 1600 km: 20 (15)% <i>90 - 500 km: 10 (5)%; 500 - 700 km: 15 (10) % 700 - 1600 km: 20 (15)%</i>	IORD-1 Recommendation
<i>IN-SITU DENSITY</i>	<i>to meet accuracy requirement at all altitudes (see notes)</i>	Recommendation

Justification:

- Consistency with validated US Space Command requirement.



IORD-1 EDR Changes

(Changes indicated in *Red Italics*)

ORBITAL DRAG - ATMOSPHERIC DENSITY

Solar EUV

RANGE	5 (1) to 130 (175) nm in 4 (10) channels <i>4 (12) wavelength bands, covering the region 5 - 103 (175) nm:</i> <i>0.0001 - 0.0200 W/m²</i> <i>Lyman Alpha: 0.0010 - 0.0200 W/m²</i>	IORD-1 Recommendation
ACCURACY	greater of 10 ⁻⁴ (5x10 ⁻⁵) W/m ² or 20% (10%) <i>10% (5%)</i>	IORD-1 Recommendation

Justification:

- The range specified should cover a solar flux range, in addition to the bands required to measure this flux range. The wavelength bands are referenced in “Space Environmental Monitoring Requirements for Polar Orbiting Spacecraft”. The EUV heating of the upper atmosphere is a function of the product of the EUV flux per wavelength interval and the interval-averaged cross sections summed over the EUV spectrum. The wavelength intervals were chosen to optimize the correspondence between large cross sections and strong flux features.
- The accuracy was derived from the threshold and objective operational density requirements based on the sensitivity of heating to EUV fluxes and the sensitivity of density to heating.



IORD-1 EDR Changes

(Changes indicated in *Red Italics*)

ORBITAL DRAG - ATMOSPHERIC DENSITY

Neutral Winds

<i>COVERAGE</i>	<i>50 - 90 deg latitude</i>	Recommendation
<i>VERTICAL RANGE</i>	<i>200 - 400 km</i>	Recommendation
<i>VERTICAL RESOLUTION</i>	<i>20 (10) km</i>	Recommendation
<i>MEASUREMENT RANGE</i>	<i>+/- 1000 (1500) m/s</i>	Recommendation
<i>ACCURACY</i>	<i>10 (5) %</i>	Recommendation

Justification:

- The drag force is related to the velocity of the satellite (or debris) relative to the wind velocity. At high latitudes during disturbed conditions winds can be a 20 % effect relative to no-wind conditions.
- The required accuracy is commensurate with the threshold and objective requirements for neutral density profiles.



BRIEFING OUTLINE

ORBITAL DRAG - ATMOSPHERIC DENSITY

**BACKGROUND
CONOPS**

NPOESS EDRs



**PRIORITIZATION
SUMMARY**



EDR PRIORITIZATION SCHEME

ORBITAL DRAG - ATMOSPHERIC DENSITY

- **Class I:** Operationally Viable Solution With Demonstrated Requirements Traceability
- **Class II:** Demonstrated Operational Need But One Or More Of The Following Apply
 - » Requirements traceability uncertain
 - » CONOPs uncertain
 - » Feasibility uncertain
- **Class III:** Research Related To Meeting User's Needs
- **Class IV:** EDR Is Derived From Other EDRs
- **Class V:** No Need For This EDR

**Class I & II EDRs Rated For Mission Impact
(Low/Med/High)**



PRIORITIZATION

Orbital Drag - Atmospheric Density

ORBITAL DRAG - ATMOSPHERIC DENSITY

SES EDRs	Category	Priority
Auroral Boundary	Class III	5
Auroral Energy Deposition		
Auroral Imagery	Class III	4
Electric Field		
Electron Density Profile	Class III	3
Geomagnetic Field		
In-situ Ion Drift	Class III	3
In-situ Plasma Density		
In-situ Plasma Fluctuations	Class III	3
In-situ Plasma Temperature		
Ionospheric Scintillation	Class III	3
Neutral Density Profiles		
Energetic Particles	Class II/High	1
Cosmic Rays		
Solar EUV Flux	Class III	2
Supra-thermal / Auroral particles		
Upper Atmospheric Airglow	Class III	6
Neutral Winds		



BRIEFING OUTLINE

ORBITAL DRAG - ATMOSPHERIC DENSITY

BACKGROUND

CONOPS

NPOESS EDRs

PRIORITIZATION



SUMMARY



SUMMARY

ORBITAL DRAG - ATMOSPHERIC DENSITY

NPOESS has a role in providing space environment sensing support for required accuracy improvement in neutral density specification and prediction



ORBITAL DRAG - ATMOSPHERIC DENSITY

BACKUP SLIDES



ORBITAL DRAG - ATMOSPHERIC DENSITY

TRD RECOMMENDATIONS



4.1.6.7.4 Electric Field Atmospheric Density

ORBITAL DRAG - ATMOSPHERIC DENSITY

Systems Capabilities	Thresholds	Objectives
<i>Coverage</i>	<i>Polar/Auroral (>abs val(40 deg) lat)</i>	<i>Global</i>
<i>Horizontal Resolution</i>	<i>0.1 deg</i>	<i>0.1 deg</i>
<i>Mapping Accuracy</i>	<i>1.0 km</i>	<i>1.0 km</i>
Measurement Range	0 - 150 mV/m	0 - 250 mV/m
Measurement Precision	<i>+/- 2%</i>	<i>+/- 1%</i>
Measurement Accuracy	<i>+/-5%</i>	<i>+/-2%</i>
<i>Timeliness*</i>	<i>2 hours</i>	<i>30 minutes</i>

** Timeliness is defined as the length of time from measurement at a particular location to end of EDR creation and output*



4.1.6.7.5 Electron Density Profile Atmospheric Density

ORBITAL DRAG - ATMOSPHERIC DENSITY

Systems Capabilities	Thresholds	Objectives
<i>Coverage</i>	<i>> 50 deg lat</i>	<i>> 50 deg lat</i>
<i>Sensing Depth</i>	<i>90 - 500 km</i>	<i>90 - 500 km</i>
Horizontal Resolution		
<i>In-track</i>		
0 - 30 lat	200 km	100 km
30 - 50 lat	500 km	250 km
50 - 90 lat	100 km	50 km
Vertical Resolution		
<i>90 - 150 km</i>	<i>5 km</i>	<i>3 km</i>
<i>150 - 500 km</i>	<i>10 km</i>	<i>10 km</i>
<i>Mapping Accuracy</i>	<i>1 deg lat</i>	<i>0.5 deg lat</i>
<i>Altitude Registration</i>		
<i>90 - 150 km</i>	<i>1 km</i>	<i>0.5 km</i>
<i>150 - 500 km</i>	<i>2 km</i>	<i>1 km</i>
Measurement Range	<i>$5 \times 10^{10} - 10^{13} \text{ m}^{-3}$</i>	<i>$1 \times 10^{10} - 10^{13} \text{ m}^{-3}$</i>
<i>Measurement Precision</i>	<i>+/-5%</i>	<i>+/-2%</i>
Measurement Accuracy	<i>+/-10 %</i>	<i>+/-5%</i>
<i>Timeliness</i>	<i>2 hours</i>	<i>30 minutes</i>



4.1.6.7.12 Neutral Density Profile Atmospheric Density

ORBITAL DRAG - ATMOSPHERIC DENSITY

Systems Capabilities	Thresholds	Objectives
<i>Coverage</i>	<i>Global</i>	<i>Global</i>
Sensing Depth	<i>90 - 800 km</i>	90 - 1600 km
Horizontal Resolution		
In-Track	500 km	<i>250 km</i>
<i>Cross-Track</i>	<i>2500 km</i>	<i>1250 km</i>
Vertical Resolution		
90 - 120 km	<i>5 km</i>	0.5 km
> 120 km	<i>5 km</i>	3 km
<i>Mapping Accuracy</i>	<i>1 deg lat</i>	<i>0.5 deg lat</i>
<i>Altitude Registration</i>		
90 - 500 km	<i>1 km</i>	<i>0.5 km</i>
500 - 700 km	<i>1.5 km</i>	<i>1 km</i>
700 - 1600 km	<i>2 km</i>	<i>1.5 km</i>
Measurement Range	$3 \times 10^{-18} - 2 \times 10^{-28} \text{ kg/m}^3$	$3 \times 10^{-18} - 2 \times 10^{-28} \text{ kg/m}^3$
<i>Measurement Precision</i>	<i>+/-5%</i>	<i>+/-1%</i>
Measurement Accuracy		
90 - 500 km	<i>+/- 10%</i>	+/- 5%
500 - 700 km	<i>+/- 15%</i>	+/- 10%
700 - 1600 km	+/- 20%	+/- 15%
<i>Timeliness</i>	<i>2 hours</i>	<i>30 minutes</i>



4.1.6.7.15 Solar EUV Atmospheric Density

ORBITAL DRAG - ATMOSPHERIC DENSITY

Systems Capabilities	Thresholds	Objectives
Measurement Range (<i>flux measured in each wavelength range</i>)		
	4 wavelength bands, covering the region 5 - 103 nm: <i>0.0001 - 0.0200 W/m²</i>	<i>12</i> wavelength bands, covering the region 5 - 175 nm: <i>0.00003 - 0.0200 W/m²</i>
<i>Lyman Alpha</i>	<i>0.0010 - 0.0200 W/m²</i>	<i>0.0010 - 0.0200 W/m²</i>
Measurement Resolution		
	<i>4 wavelength bands, covering the region 5 - 103 nm</i>	<i>12 wavelength bands, covering the region 5 - 175 nm</i>
<i>Lyman Alpha</i>	<i>0.0002 W/ m²</i>	<i>0.0002 W/ m²</i>
Measurement Accuracy	<i>+/- 10%</i>	<i>+/- 5%</i>
<i>Refresh</i>	<i>6 hours</i>	<i>1 measurement per orbit</i>



4.1.6.7.16 Precipitating Particles * Atmospheric Density

ORBITAL DRAG - ATMOSPHERIC DENSITY

Systems Capabilities	Thresholds	Objectives
<i>Coverage</i>	<i>>50 deg lat</i>	<i>>50 deg lat</i>
<i>Horizontal Resolution</i>	<i>10 km</i>	<i>10 km</i>
<i>Mapping Accuracy</i>	<i>1 km</i>	<i>1 km</i>
Measurement Range		
<i>Characteristic</i> Energy	<i>100 eV to 20 keV</i>	<i>30 eV to 100 keV</i>
Flux	$10^8 - 10^{15} \text{ m}^{-2} \text{ sec}^{-1} \text{ ster}^{-1} \text{ keV}^{-1}$	<i>$10^8 - 10^{15} \text{ m}^{-2} \text{ sec}^{-1} \text{ ster}^{-1} \text{ keV}^{-1}$</i>
Measurement Precision		
<i>Characteristic</i> Energy	$\Delta E/E = \pm 0.2$	$\Delta E/E = \pm 0.1$
Flux	$\pm 5\%$	$\pm 1\%$
Measurement Accuracy	<i>$\pm 10\%$</i>	<i>$\pm 5\%$</i>
<i>Timeliness</i>	<i>2 hours</i>	<i>30 minutes</i>

* this is a desired measurement, not necessary now that the group has specified auroral energy deposition



In Situ Composition *

Atmospheric Density

ORBITAL DRAG - ATMOSPHERIC DENSITY

Systems Capabilities	Thresholds	Objectives
<i>Horizontal Resolution</i>		
<i>In-Track</i>	<i>500 km</i>	<i>250 km</i>
<i>Cross-Track</i>	<i>2500 km</i>	<i>1250 km</i>
<i>Measurement Range</i>		
<i>O</i>	<i>$10^{10} - 10^{14} \text{ m}^{-3}$</i>	<i>$10^{10} - 10^{14} \text{ m}^{-3}$</i>
<i>He</i>	<i>$10^{11} - 10^{13} \text{ m}^{-3}$</i>	<i>$10^{11} - 10^{13} \text{ m}^{-3}$</i>
<i>Measurement Accuracy</i>		
<i>O</i>	<i>+/- 10%</i>	<i>+/- 5%</i>
<i>He</i>	<i>+/- 15%</i>	<i>+/- 10%</i>
<i>Timeliness</i>	<i>2 hours</i>	<i>30 minutes</i>

* this has been combined as an objective with Neutral Density Profile



SATELLITE DESIGN AND ANOMALY RESOLUTION

Task 2 - EDR Assessment & Validation

Satellite Design & Anomaly Resolution Working Group

Members

Bill Denig, IPO

Gary Mullen, AFRL/GP

Steve Cahanin, 50 WS/DO

Phil Anderson, Aerospace

Harry Koons, Aerospace

Dave Speich, NOAA/SEC

Michelle Thomsen, LANL

Steve Pearson, NASA/MSFC

Dave Evans, NOAA/SEC



BRIEFING OUTLINE

SATELLITE DESIGN AND ANOMALY RESOLUTION



BACKGROUND

- Task 2 Objectives
- User Needs Assessment
- Space Environmental Effects
- Space Environment Support

CONOPS

NPOESS EDRs

PRIORITIZATION

EDR SENSOR DATA RECORDS

SUMMARY



BACKGROUND

Task 2 Objectives

SATELLITE DESIGN AND ANOMALY RESOLUTION

Task 2 Objectives

- **Document existing CONOPS (data, models, methods)**
- **Identify future CONOPS**
- **Determine contributions from NPOESS**
- **Prioritize NPOESS EDRs**



BACKGROUND

User Needs Assessment

SATELLITE DESIGN AND ANOMALY RESOLUTION

User Needs Assessment

- **Space environment data required for anomaly resolution (real-time to post-event)**
 - **global data too coarse a grid - model dependencies**
 - **satellite onboard data preferred**
- **Space hazard prediction required for manned spaceflight and radiation dose for airline personnel**
- **Long-term representative data sets required for satellite design**



BACKGROUND

Space Environmental Effects

SATELLITE DESIGN AND ANOMALY RESOLUTION

Space Environmental Effects

- **Surface Charging**
- **Deep Dielectric Charging**
- **Single Event Upsets**
- **Radiation Dose**
- **Magnetic Perturbations**
- **High-Voltage / Plasma Interactions**
- **Space Debris**
- **Material Degradation**



BACKGROUND

Space Environment Support

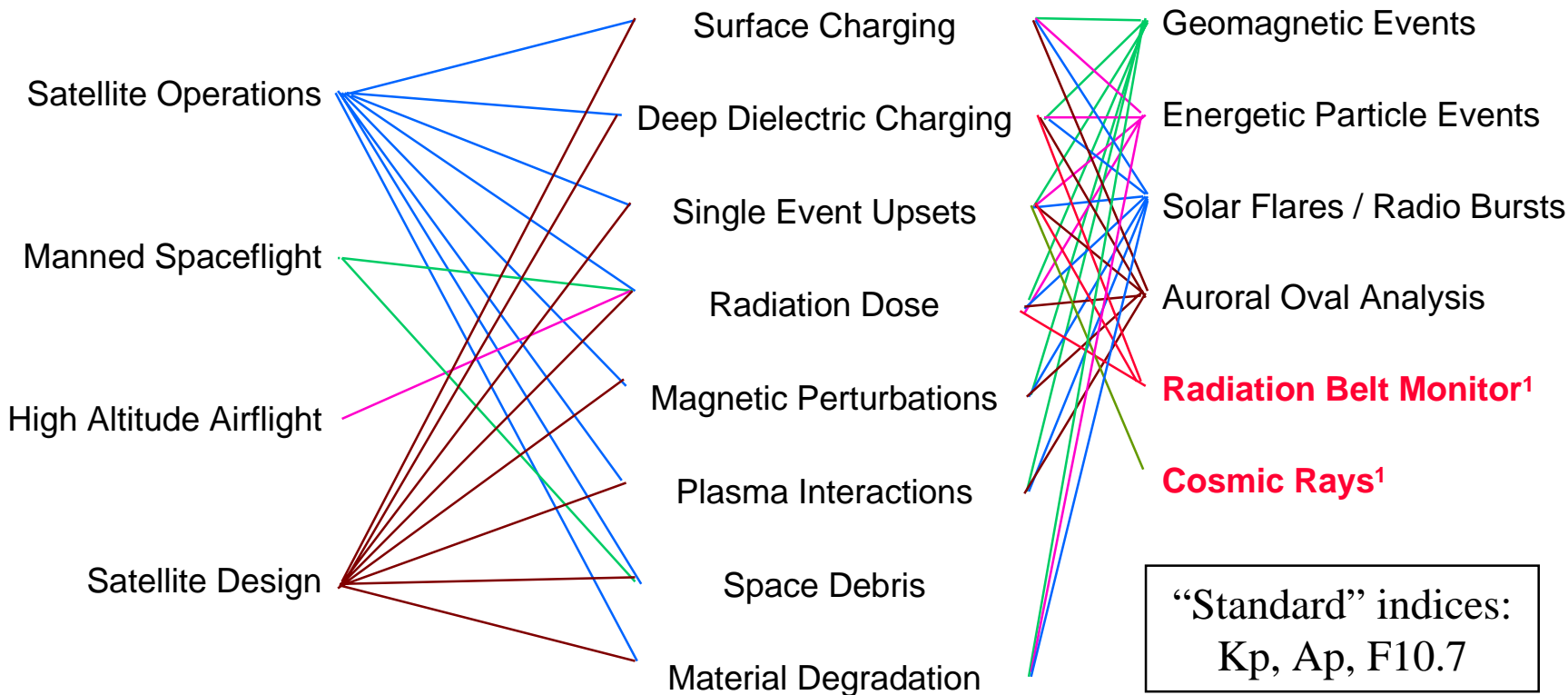
SATELLITE DESIGN AND ANOMALY RESOLUTION

Space Environment Support

Mission

Effects

Products



¹Identified concern - future product (?)



BRIEFING OUTLINE

SATELLITE DESIGN AND ANOMALY RESOLUTION

→ BACKGROUND CONOPS

- Satellite Anomaly Resolution
- Manned Spaceflight
- Satellite Design
- Standard Products

NPOESS EDRs

PRIORITIZATION

EDR SENSOR DATA RECORDS

SUMMARY



CONCEPT OF OPERATIONS

Status (Current, Revised, Future)

SATELLITE DESIGN AND ANOMALY RESOLUTION

Satellite Anomaly Resolution

- **Current** - Standard products and tailored support
- **Revised** - Real-time data to users, Expert system
- **Future** - In-situ health & status, Radiation belt support

Manned Spaceflight & Aircraft Operations

- **Current** - Direct support to NASA / DoD
- **Revised** - No change
- **Future** - Low altitude radiation support

Satellite Design

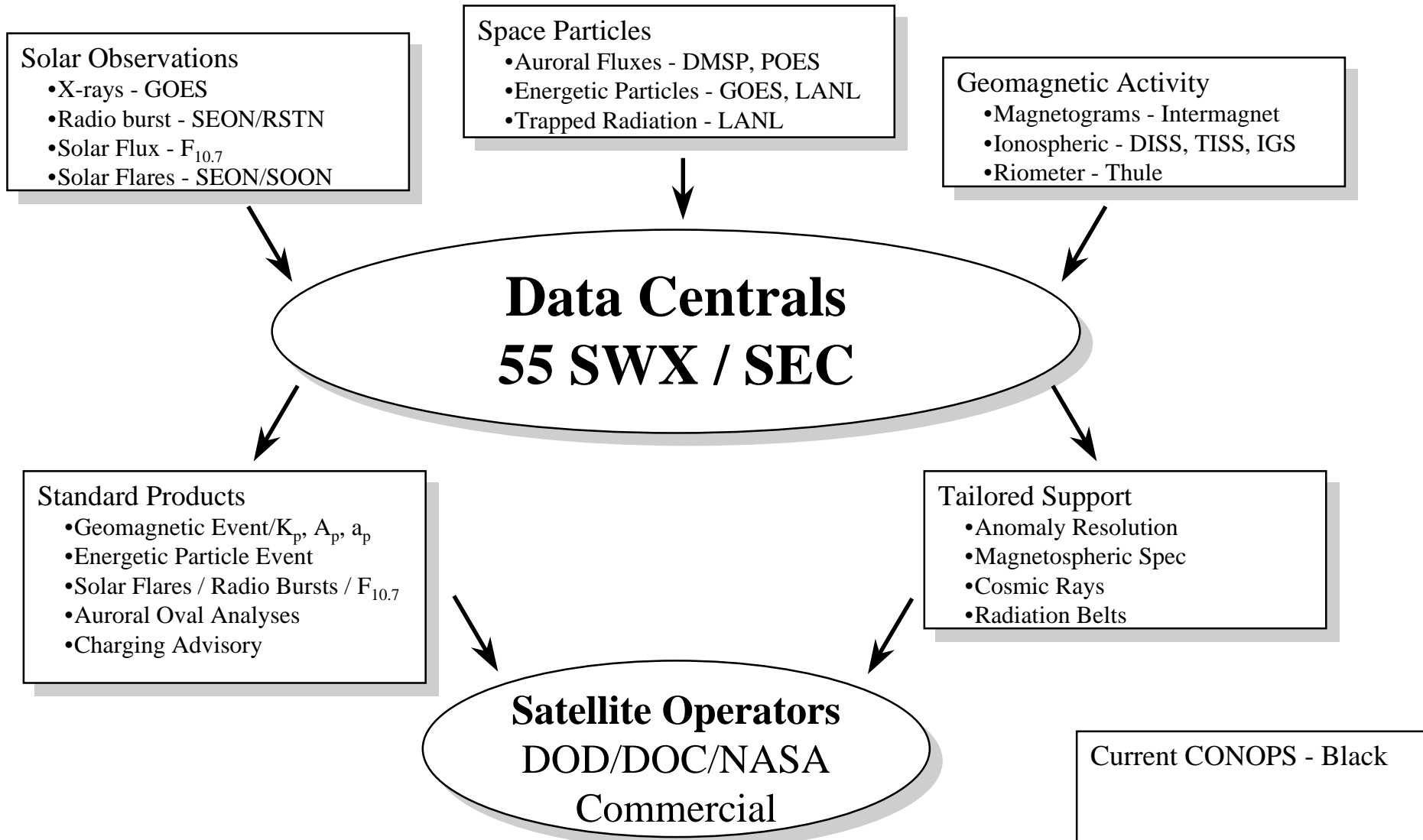
- **Current** - Limited overarching support
- **Revised** - Centralized support network
- **Future** - No change



CONCEPT OF OPERATIONS

Satellite Anomaly - Current

SATELLITE DESIGN AND ANOMALY RESOLUTION

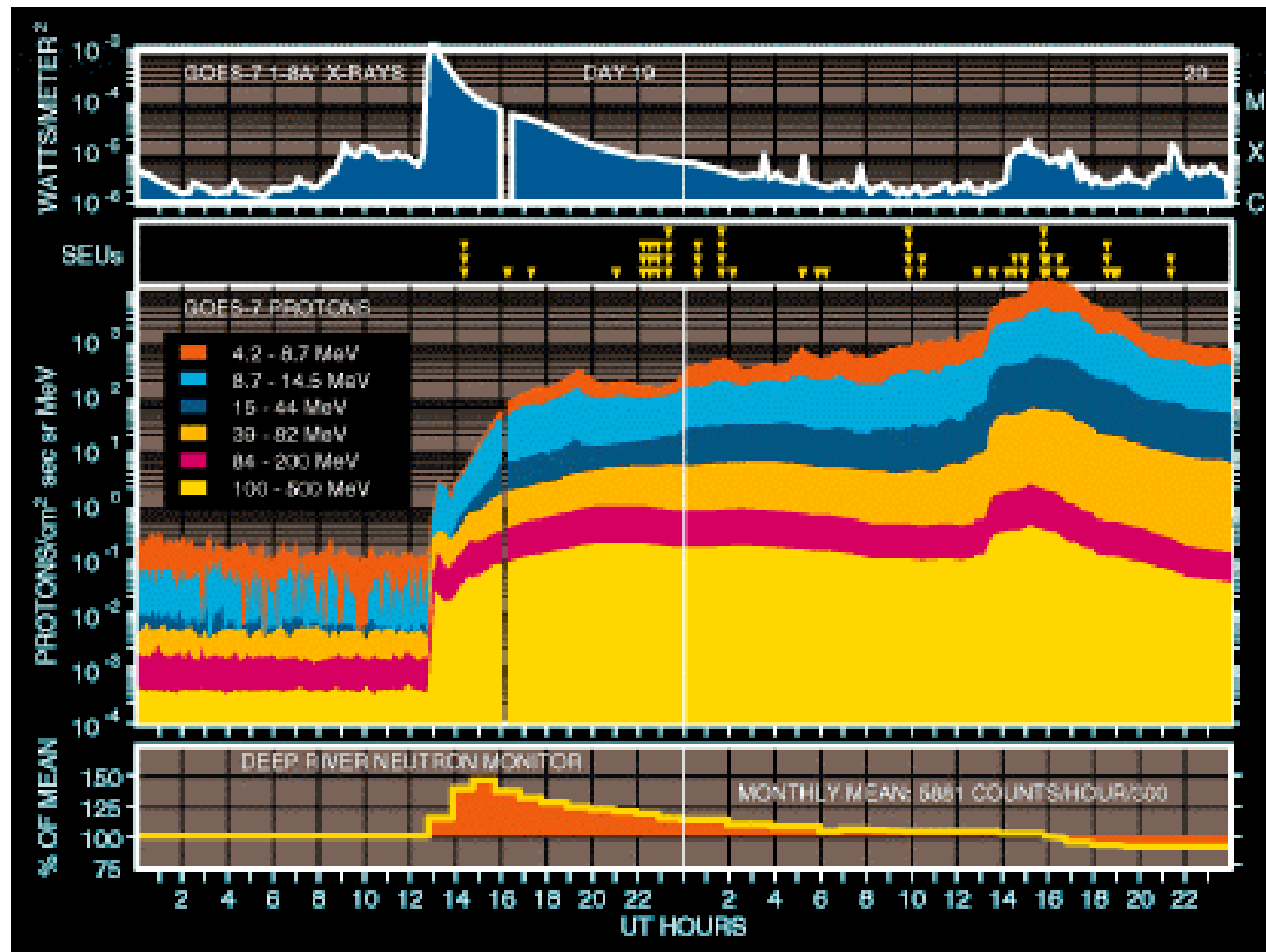




CONCEPT OF OPERATIONS

Satellite Anomaly - Current

SATELLITE DESIGN AND ANOMALY RESOLUTION

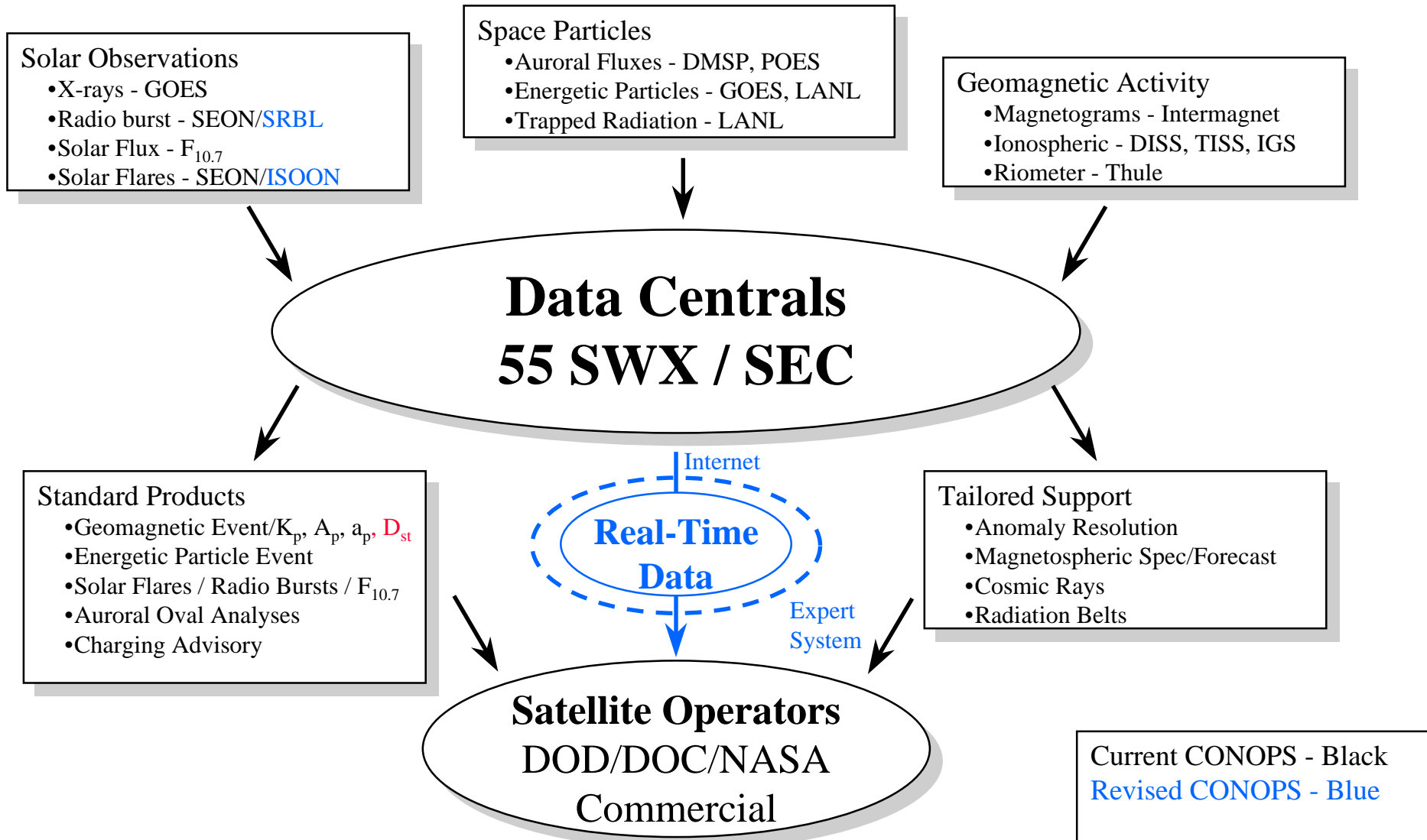




CONCEPT OF OPERATIONS

Satellite Anomaly - Revised

SATELLITE DESIGN AND ANOMALY RESOLUTION

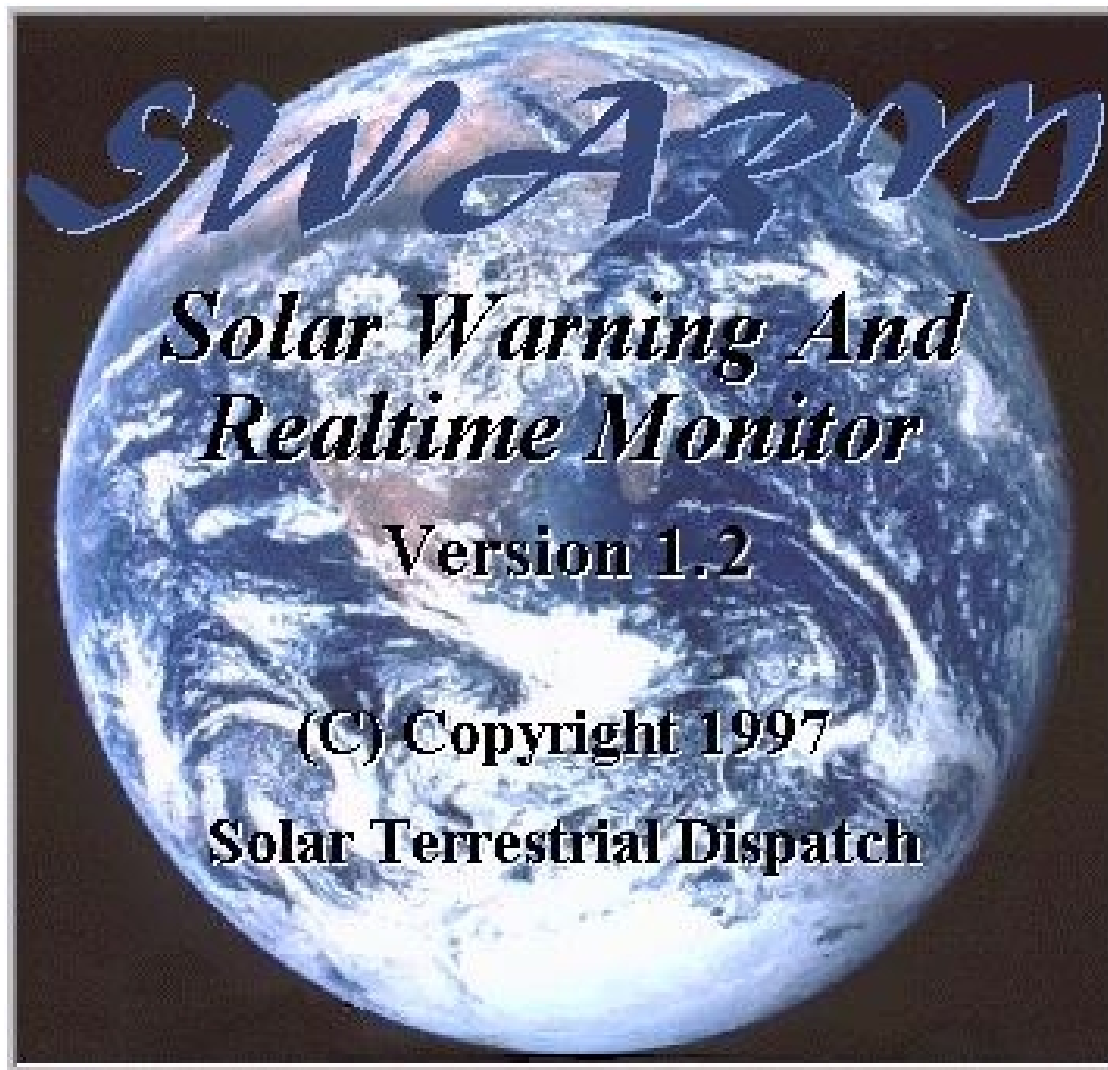




CONCEPT OF OPERATIONS

Satellite Anomaly - Revised

SATELLITE DESIGN AND ANOMALY RESOLUTION

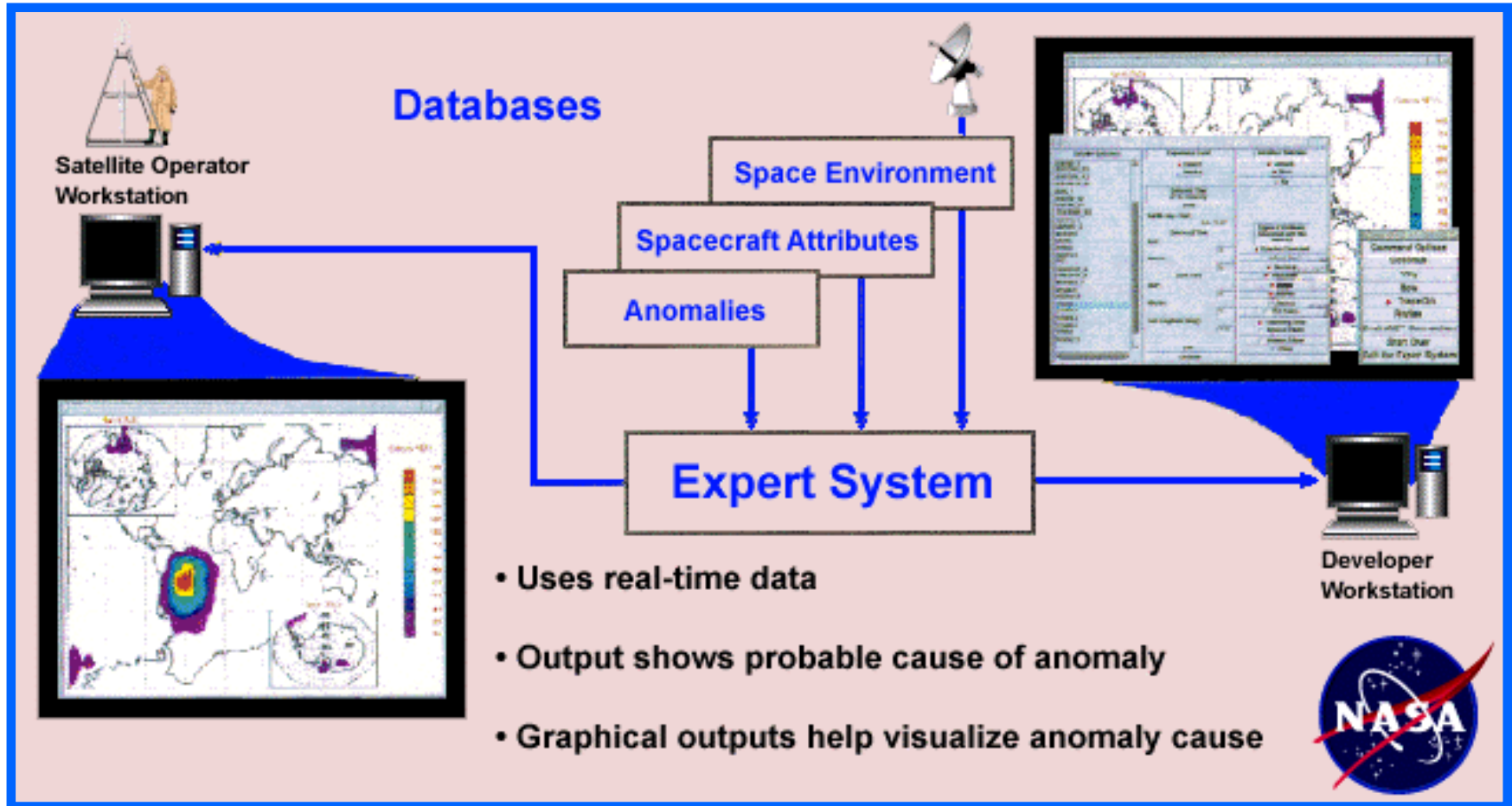




CONCEPT OF OPERATIONS

Satellite Anomaly - Revised

SATELLITE DESIGN AND ANOMALY RESOLUTION

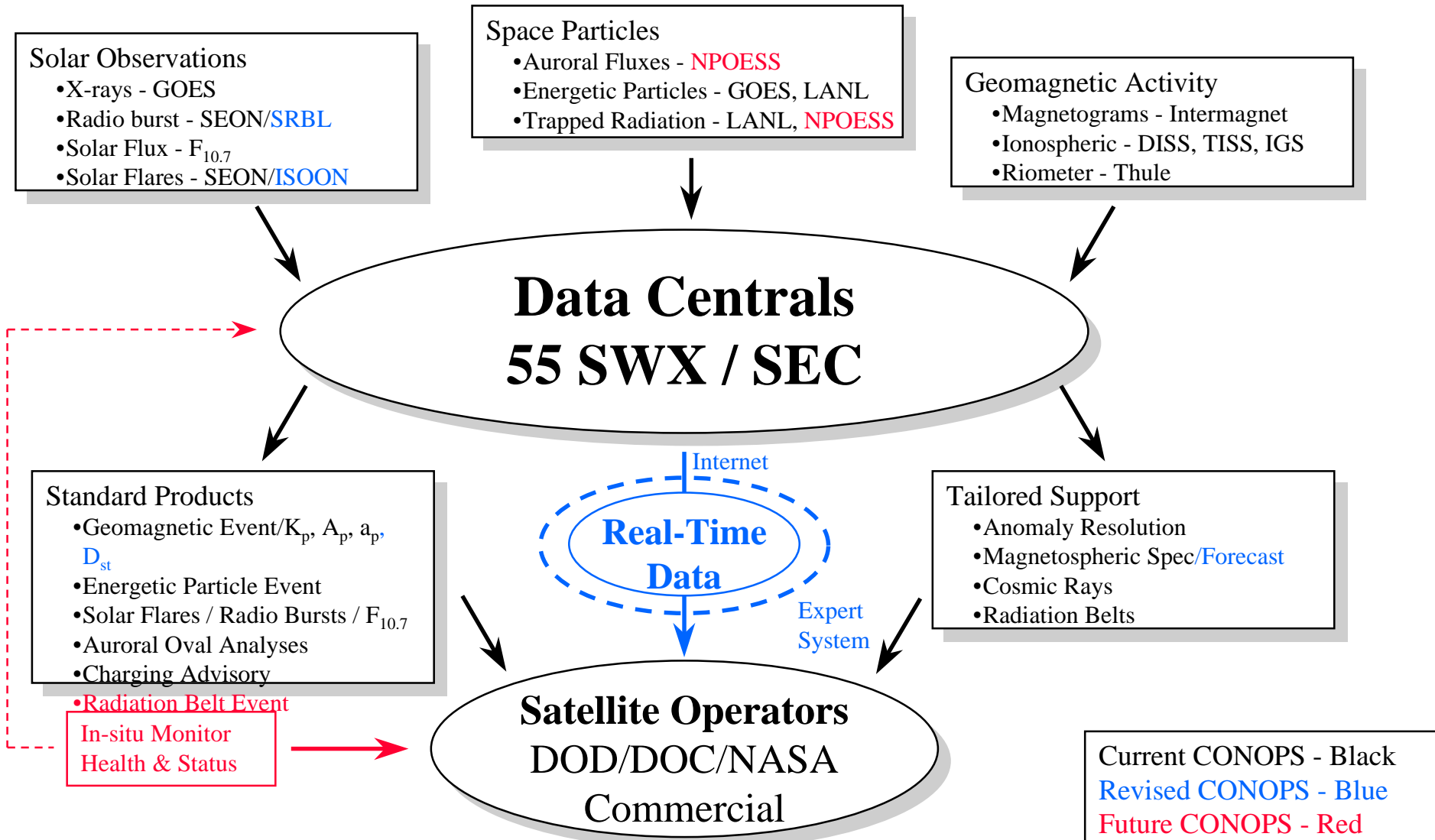




CONCEPT OF OPERATIONS

Satellite Anomaly - Future

SATELLITE DESIGN AND ANOMALY RESOLUTION

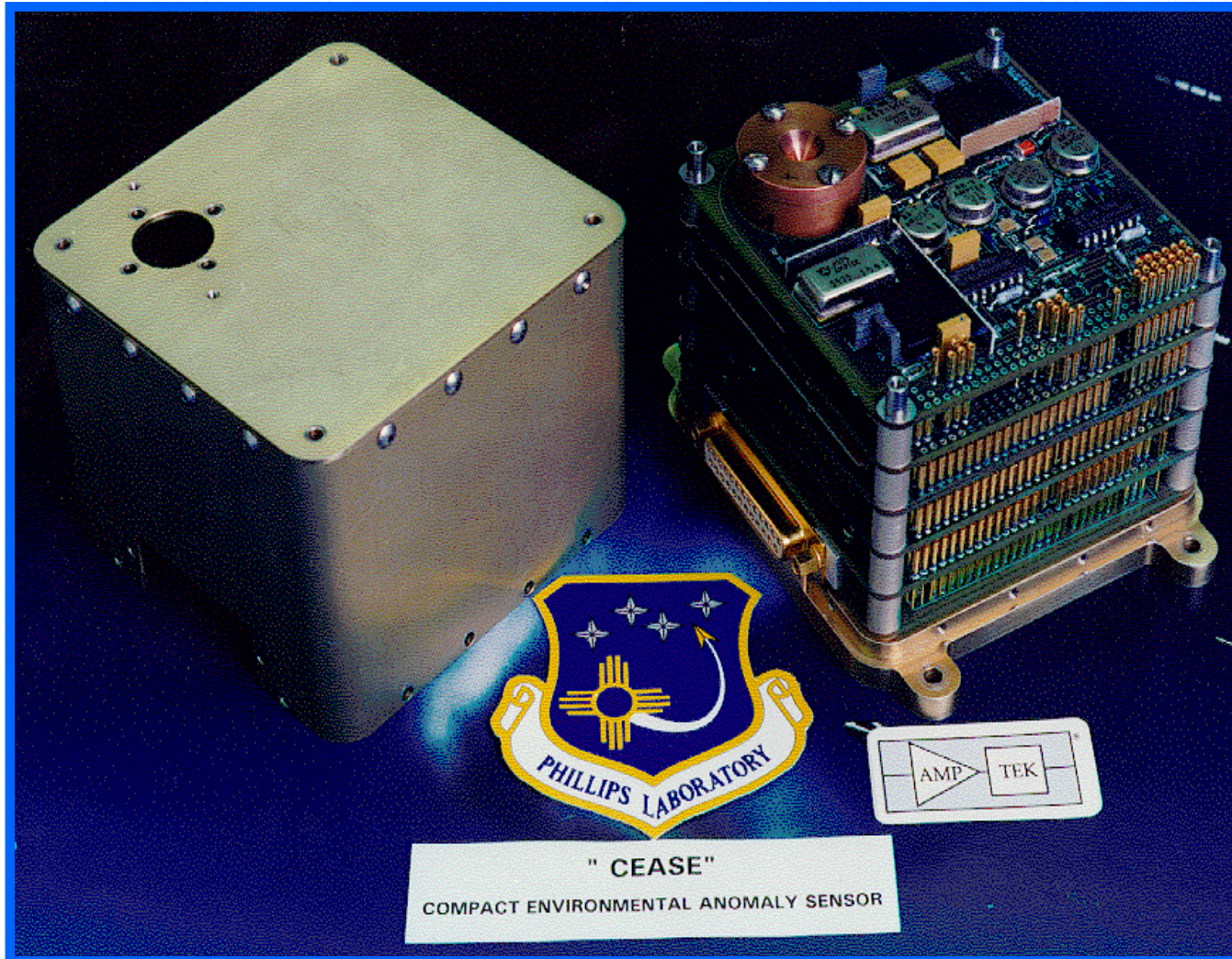




CONCEPT OF OPERATIONS

Satellite Anomaly - Future

SATELLITE DESIGN AND ANOMALY RESOLUTION

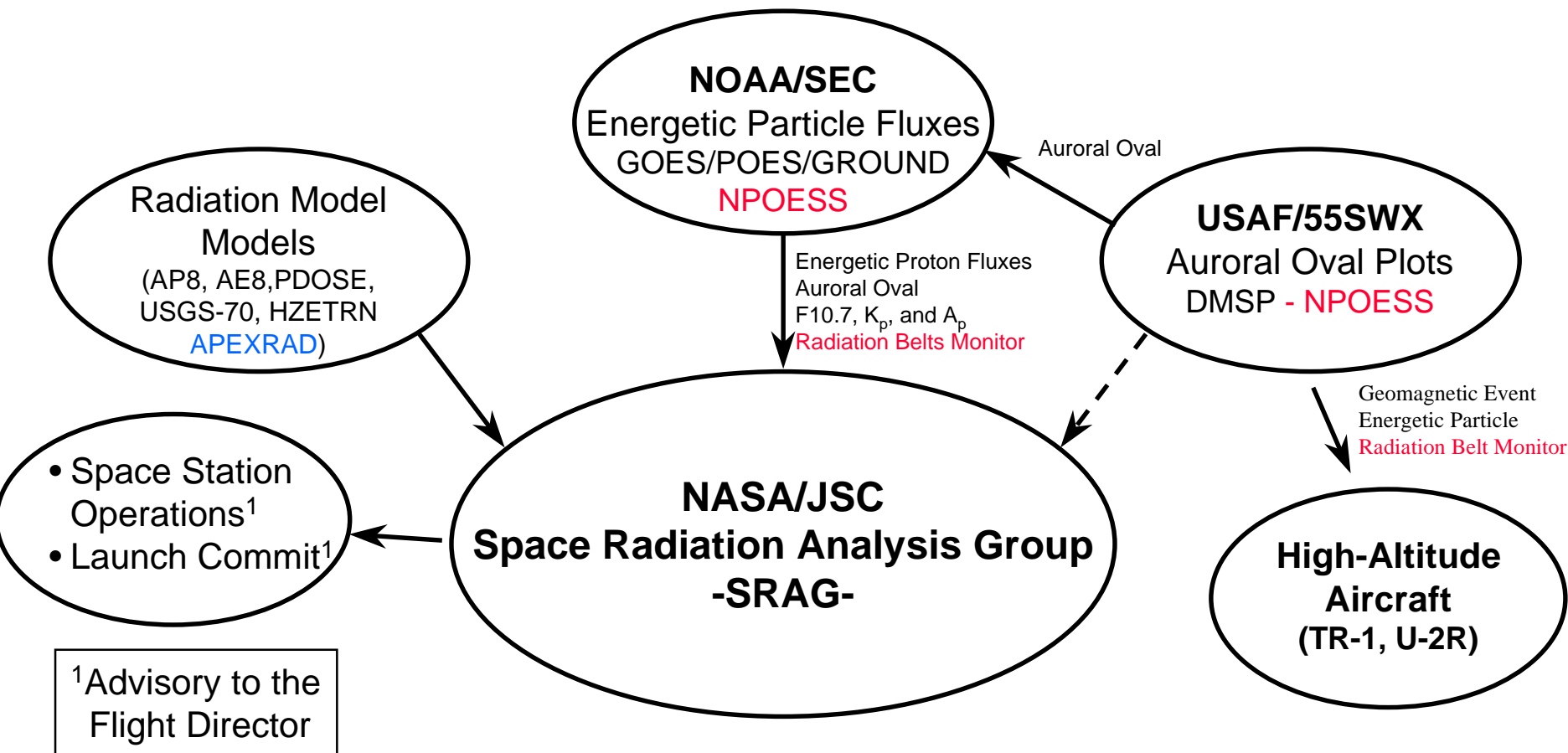




CONCEPT OF OPERATIONS

Manned Spaceflight / Aircraft Ops

SATELLITE DESIGN AND ANOMALY RESOLUTION



NOAA provides primary support for Manned Spaceflight through:

- Weather Alerts
- Forecasts
- Environmental Data Assessment

55SWX provide backup support to the SRAG

Current CONOPS - Black

Revised CONOPS - Blue

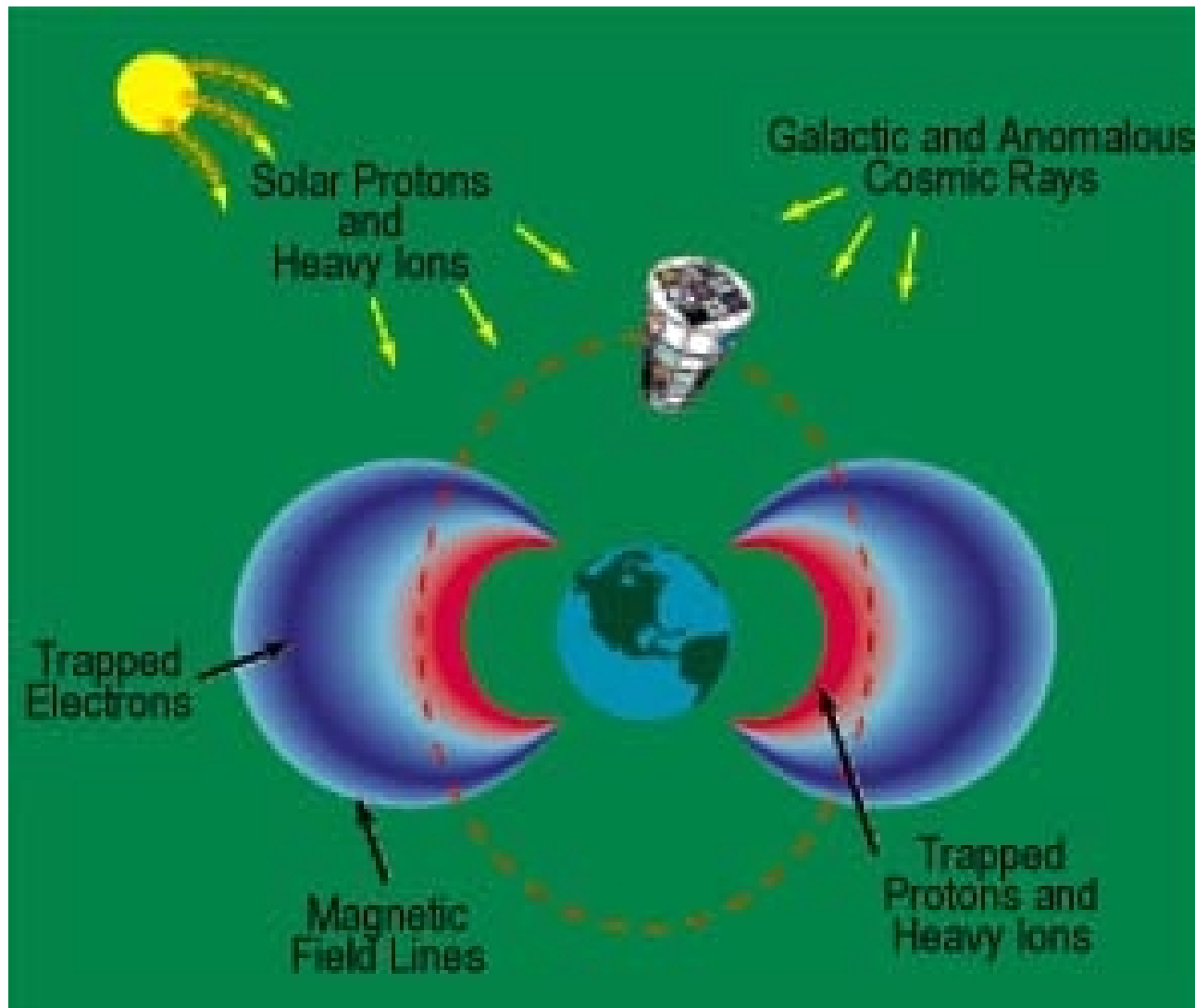
Future CONOPS - Red



CONCEPT OF OPERATIONS

Manned Spaceflight / Aircraft Ops

SATELLITE DESIGN AND ANOMALY RESOLUTION

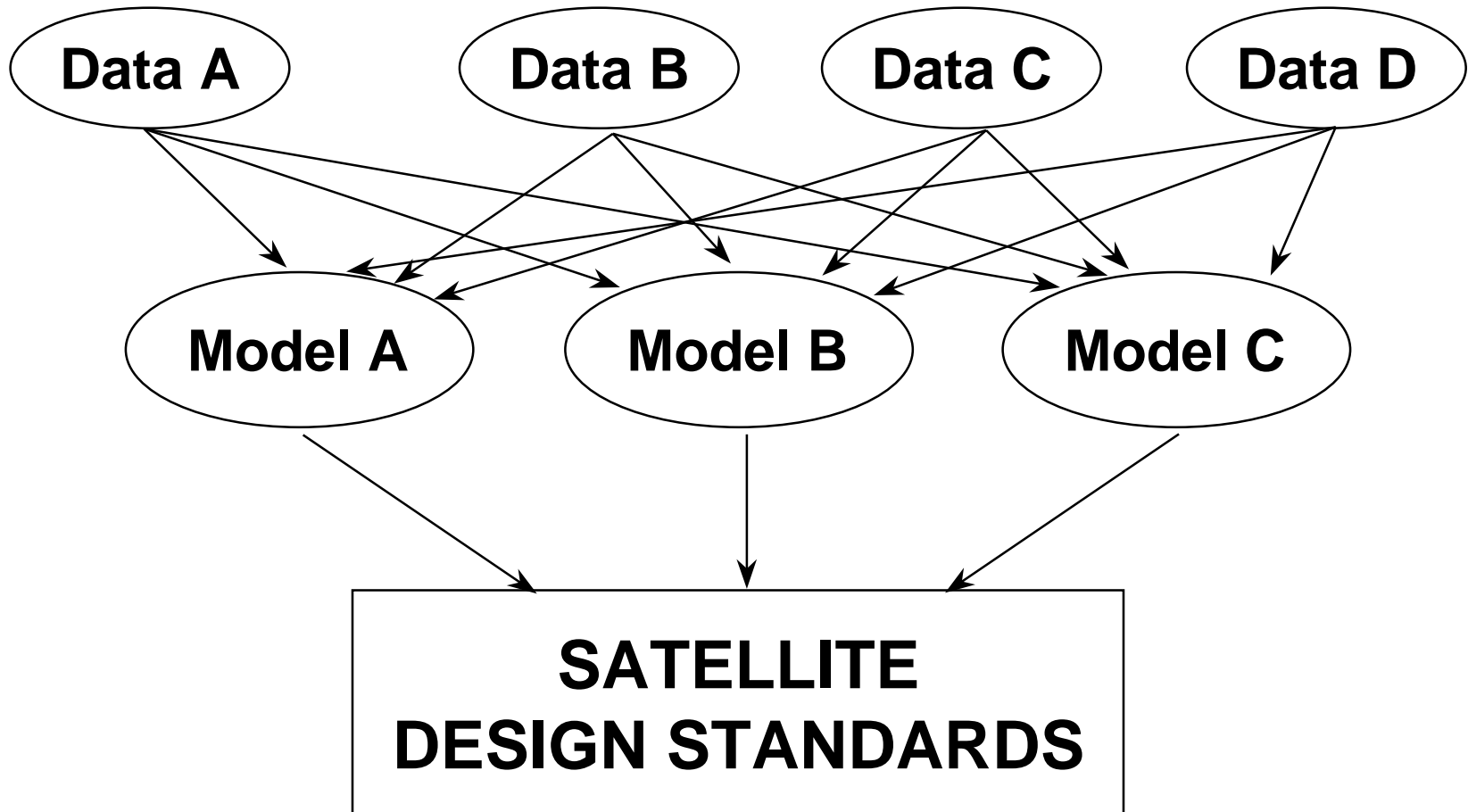




CONCEPT OF OPERATIONS

Satellite Design - Current

SATELLITE DESIGN AND ANOMALY RESOLUTION

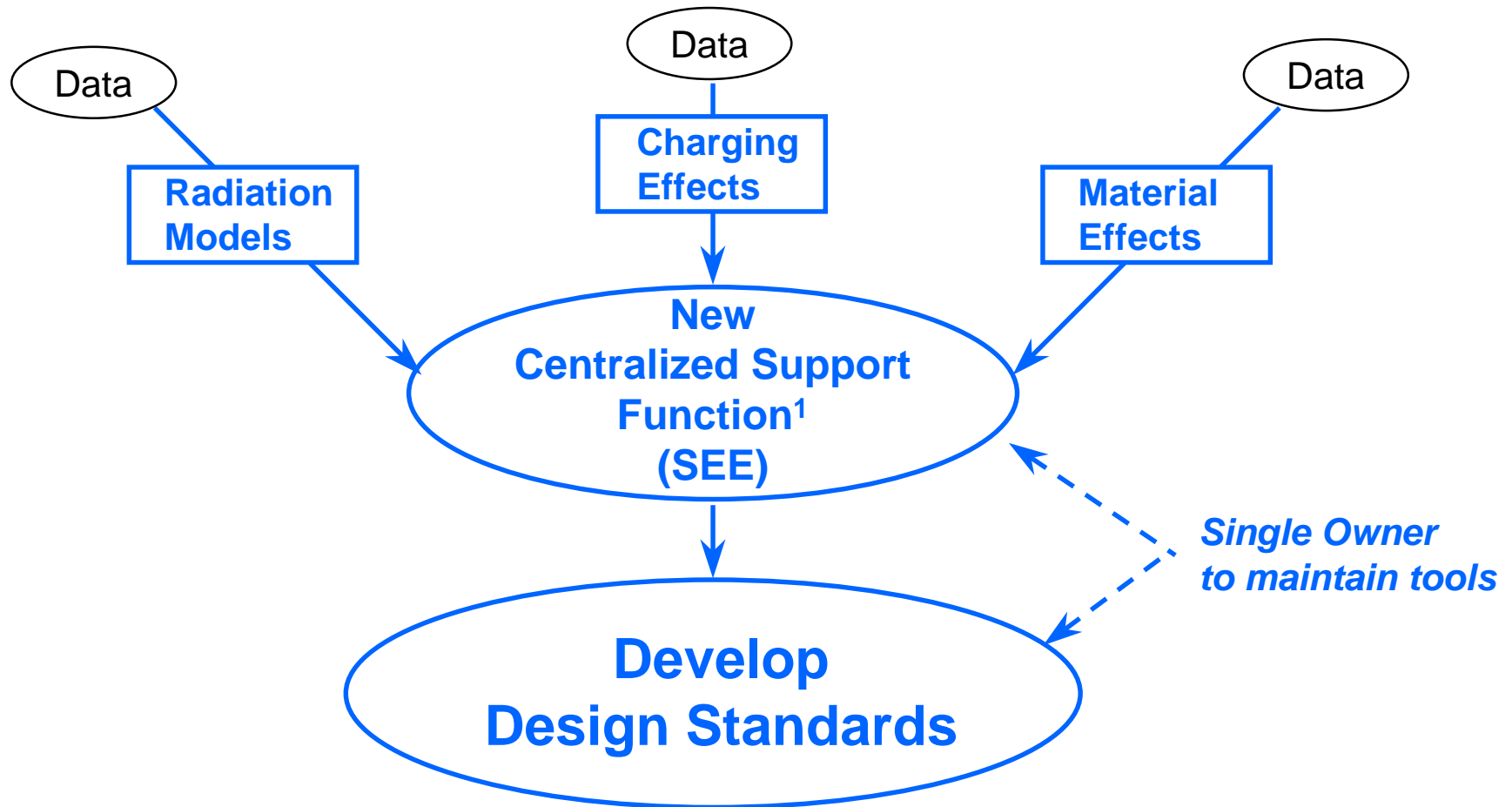




CONCEPT OF OPERATIONS

Satellite Design - Revised / Future

SATELLITE DESIGN AND ANOMALY RESOLUTION



¹Not an operational center

Current CONOPS - Black
Revised CONOPS - Blue
Future CONOPS - Red



CONCEPT OF OPERATIONS

Satellite Design - Revised / Future

SATELLITE DESIGN AND ANOMALY RESOLUTION





BRIEFING OUTLINE

SATELLITE DESIGN AND ANOMALY RESOLUTION

BACKGROUND CONOPS



NPOESS EDRs

- Effect to NPOESS EDRs
- Assigned EDRs and status
- IORD-1 versus Assigned EDRs

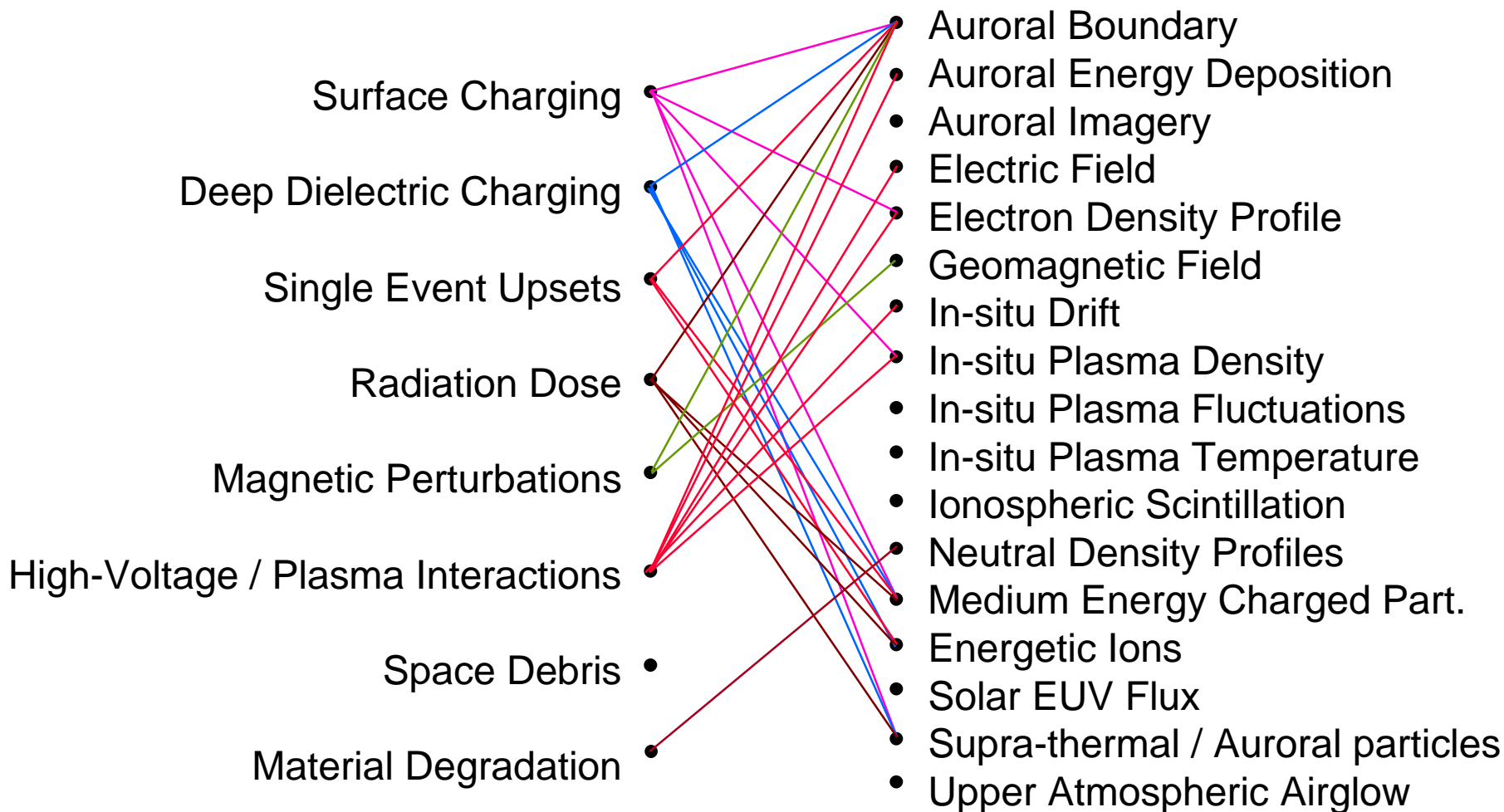
PRIORITIZATION

EDR SENSOR DATA RECORDS SUMMARY



Effect-to-NPOESS EDR Mapping

SATELLITE DESIGN AND ANOMALY RESOLUTION





Satellite Design & Anomaly Resolution

EDR Priorities: High-to-Low

SATELLITE DESIGN AND ANOMALY RESOLUTION

SES EDRs	Category	WG Comments
Supra-thermal/Auroral Part.	I/High	Determine charging environment
Auroral Boundary	I/High	Determine charging environment
Medium Energy Charged Part.	I/Moderate	Assess radiation belt / polar radiat
Auroral Energy Deposition	I/Moderate	Assess geomagnetic “stress” levels
Electron Density Profile	I/Moderate	Assess charging environment
Electric Field	II/Moderate	Assess geomagnetic “stress” levels
Geomagnetic Field	II/Low	Assess magnetic perturbations
Energetic Ions	II/Low	Assess radiation environment, polar/SAA
Neutral Density Profiles	II/Low	Atomic O specification
Auroral Imagery	n/a	Redundant - see E-field Redundant - see electron density
In-situ Drift	n/a	
In-situ Plasma Density	n/a	
In-situ Plasma Fluctuations	n/a	
In-situ Plasma Temperature	n/a	
Ionospheric Scintillation	n/a	
Solar EUV Flux	n/a	
Upper Atmospheric Airglow	n/a	



IORD-1 versus Assigned EDRs

(Changes indicated in *Red Italics*)

SATELLITE DESIGN AND ANOMALY RESOLUTION

Radiation Belt & Low Energy Solar Particles → *Medium Energy Particles*

	ENERGY	FLUX	
RANGE	30 keV - 10 MeV <i>50 keV - 10 MeV</i>	$10^5 - 10^{11} / \text{m}^2\text{-s-ster}$ <i>$10^6 (10^5) - 5 \times 10^{11} / \text{m}^2\text{-s-ster}$</i>	IORD-1 Recommendation
PRECISION	8 energy bands <i>6 energy bands</i>	5% (1%) 5% (1%)	IORD-1 Recommendations
ACCURACY		20% (10%) 20% (10%)	IORD-1 - <i>unclear</i> Recommendations

Justification:

- Low energy range covered by the supra-thermal through auroral energy EDR. In addition, raising the low energy threshold from 30 keV to 50 keV simplifies sensor design and reduces radiation damage.
- Upper flux threshold set by experience from the TIROS satellite. Lower bound set by typical dynamic ranges for solid state detectors and the total flux precisions requirement
- Reduced # of energy bands simplifies instrument design.
- Note: Radiation dose proposed as an objective measurement.

Recommended TRD Changes to Follow



IORD-1 versus Assigned EDRs (Changes indicated in *Red Italics*)

SATELLITE DESIGN AND ANOMALY RESOLUTION

Solar & Galactic Cosmic Ray Particle → *Energetic Ions*

		ENERGY	FLUX	
RANGE	protons	>10 - >1000 MeV/nucleon	$10^3 (10^2) - 10^{10} / \text{m}^2\text{-s-ster}$	IORD-1
	alpha	>10 - >1000 MeV/nucleon	$10^2 - 10^8 / \text{m}^2\text{-s-ster}$	IORD-1
	CNO	>10 - >1000 MeV/nucleon	$10^0 - 10^7 / \text{m}^2\text{-s-ster}$	IORD-1
	Fe	>10 - >1000 MeV/nucleon	$10^{-1} (10^{-3}) - 10^6 / \text{m}^2\text{-s-ster}$	IORD-1
	<i>protons</i>	<i>10 MeV - 300 MeV (400 MeV)</i>	<i>$5 \times 10^3 - 2 \times 10^9 / \text{m}^2\text{-s-ster}$</i>	<i>Recommendation</i>
PRECISION	protons	6 (8) bands	5% (1%)	IORD-1
	alpha	4 bands	5% (1%)	IORD-1
	CNO	4 bands	5% (1%)	IORD-1
	Fe	4 bands	5% (1%)	IORD-1
	<i>protons</i>	<i>6 (8) bands</i>	<i>5% (1%)</i>	<i>Recommendation</i>
ACCURACY			20% (10%)	IORD-1
			20% (10%)	Recommendation

Justification:

- Sharply reduced levels of energetic protons exist above 100 MeV.
- Flux range is compatible with modest-to-high event levels.
- **NOTE**: Alphas and heavy ions are left as objective measurements (L.E.T.).

Recommended TRD Changes to Follow



BRIEFING OUTLINE

SATELLITE DESIGN AND ANOMALY RESOLUTION

BACKGROUND

CONOPS

NPOESS EDRs



PRIORITIZATION

EDR SENSOR DATA RECORDS

SUMMARY



PRIORITIZATION

Satellite Design and Anomaly Resolution

SATELLITE DESIGN AND ANOMALY RESOLUTION

High



Supra-thermal / Auroral particles

Auroral Boundary

Medium Energy Charged Part.

Auroral Energy Deposition

Electron Density Profile (In-situ N_e)

Electric Field (In-situ Drift)

Radiation Dose (Objective)

Geomagnetic Field

Energetic Ions (Objective L.E.T.)

Neutral Density Profiles

Low



BRIEFING OUTLINE

SATELLITE DESIGN AND ANOMALY RESOLUTION

BACKGROUND

CONOPS

NPOESS EDRs

PRIORITIZATION

EDR SENSOR DATA RECORDS



SUMMARY



SUMMARY

SATELLITE DESIGN AND ANOMALY RESOLUTION

NPOESS continues to be a fundamental element of the space environment sensing function supporting the needs of the government and civil agencies.



SATELLITE DESIGN AND ANOMALY RESOLUTION

BACKUP SLIDES



SATELLITE DESIGN AND ANOMALY RESOLUTION

SUPPORTING CONOPS

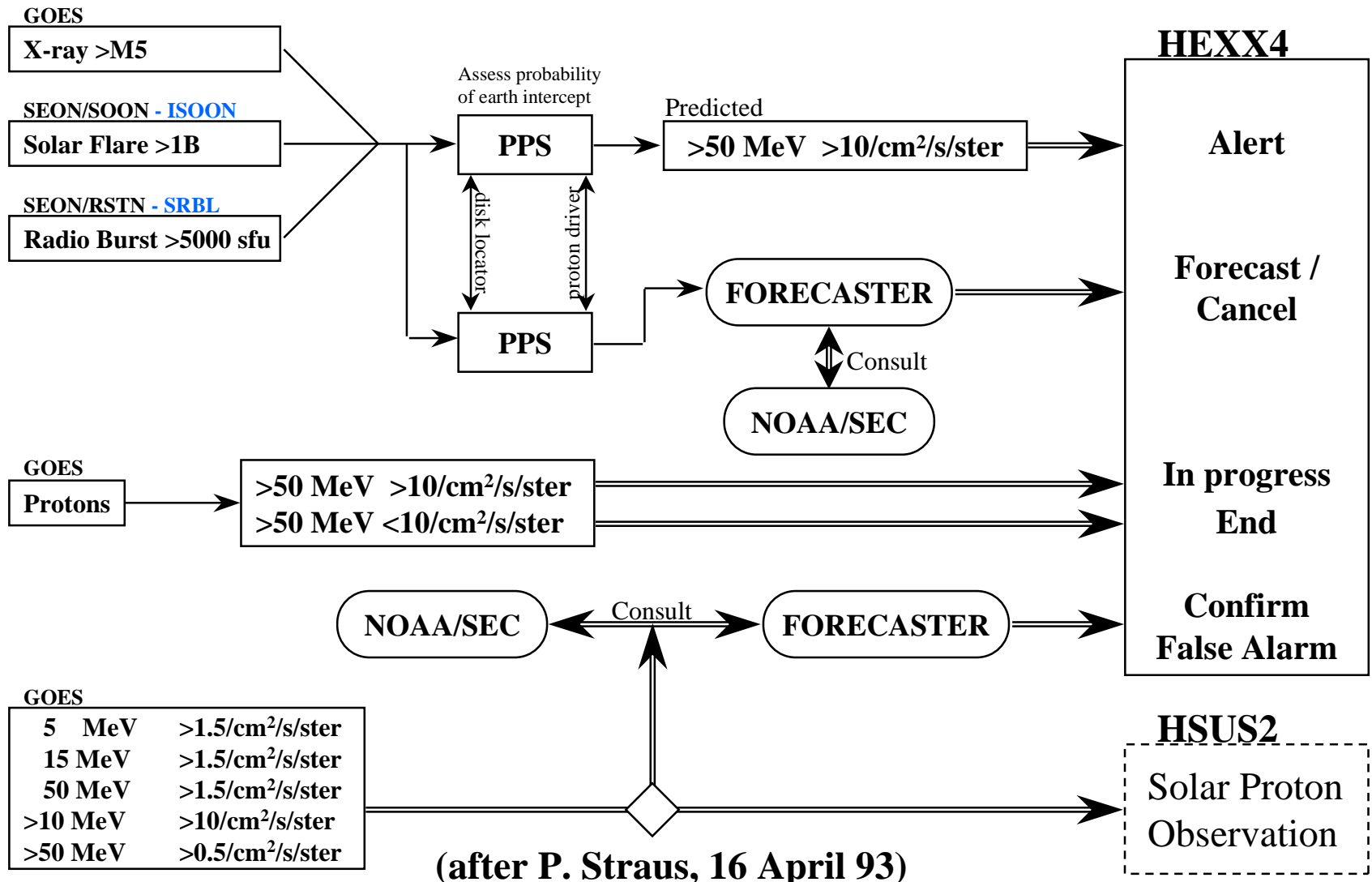


55 SWX Space Environment Product

HEXX4: Energetic Particle Event Warning

HSUS2: Solar Proton Observations

SATELLITE DESIGN AND ANOMALY RESOLUTION

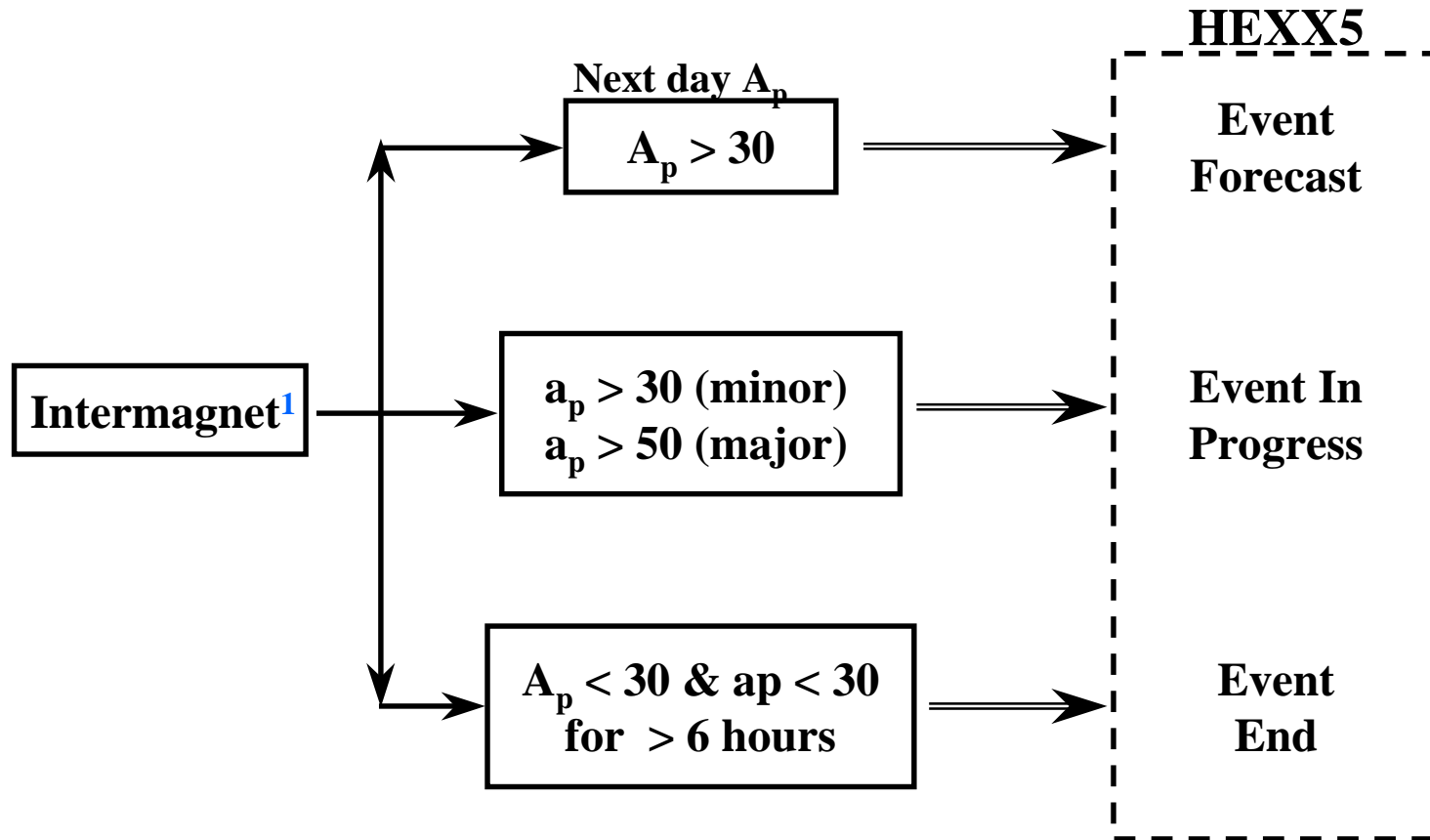




55 SWX Space Environment Product

HEXX5: Geomagnetic Event

SATELLITE DESIGN AND ANOMALY RESOLUTION



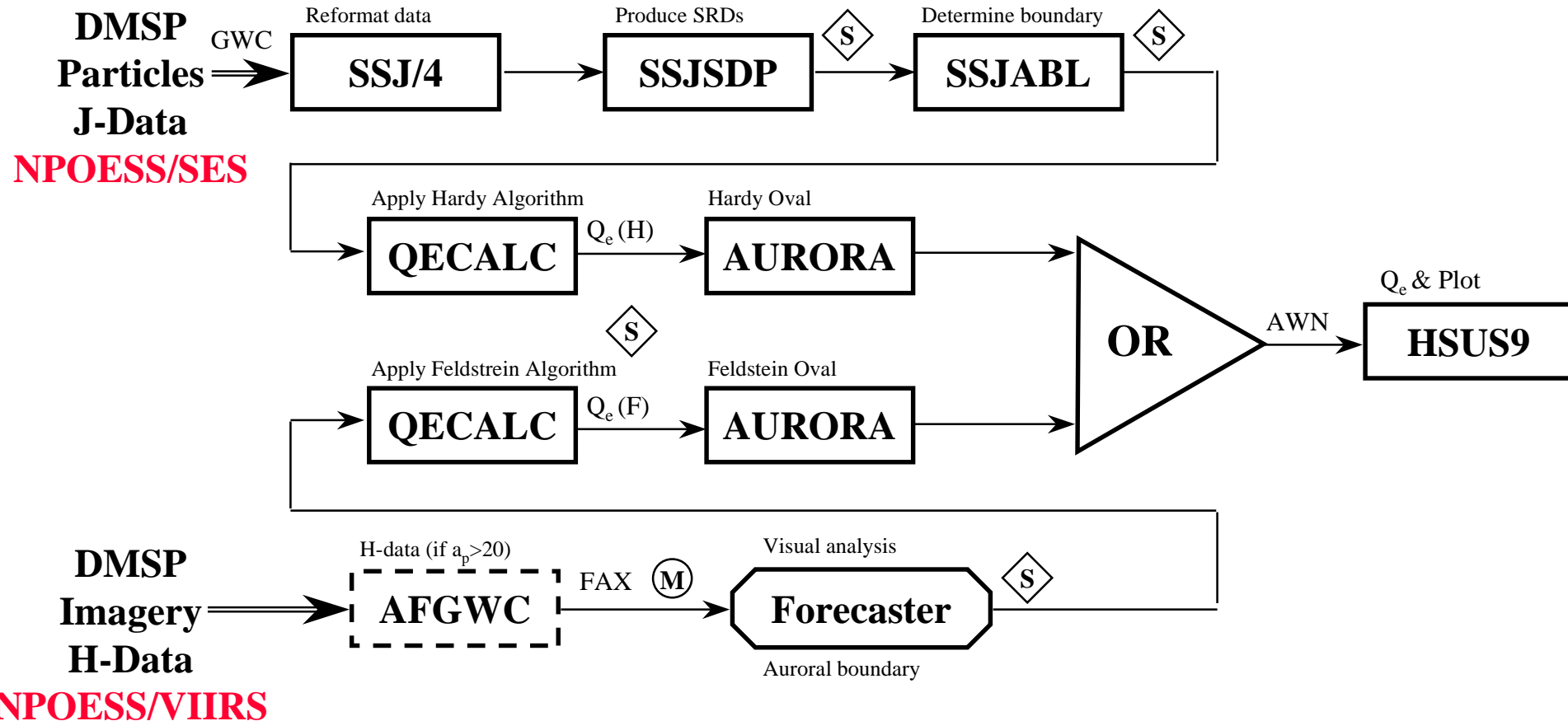
¹Recommend adding Eastern Hemisphere Stations



55 SWX Space Environment Product

HSUS9: Auroral Oval Analysis

SATELLITE DESIGN AND ANOMALY RESOLUTION



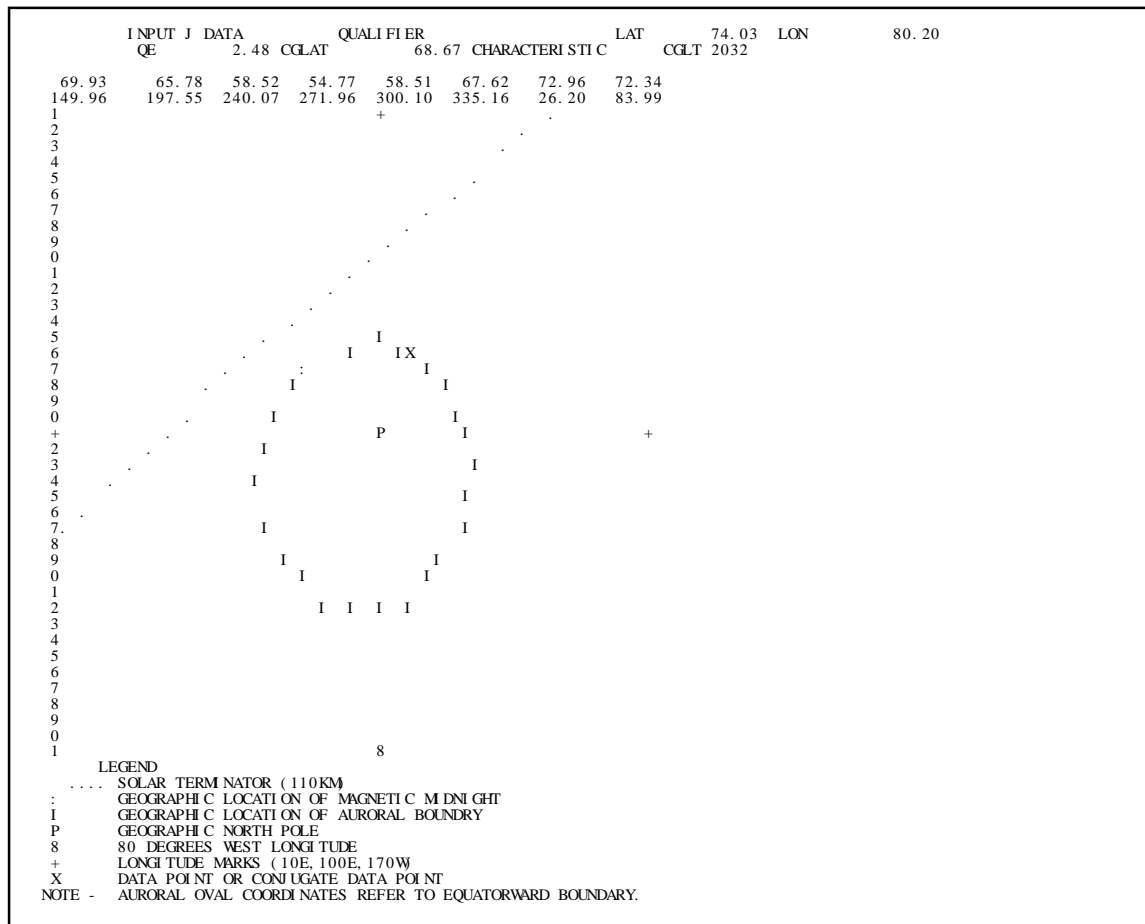
(after P. Straus, 16 April 93)



55 SWX Space Environment Product

HSUS9: Auroral Oval Analysis (Current)

SATELLITE DESIGN AND ANOMALY RESOLUTION

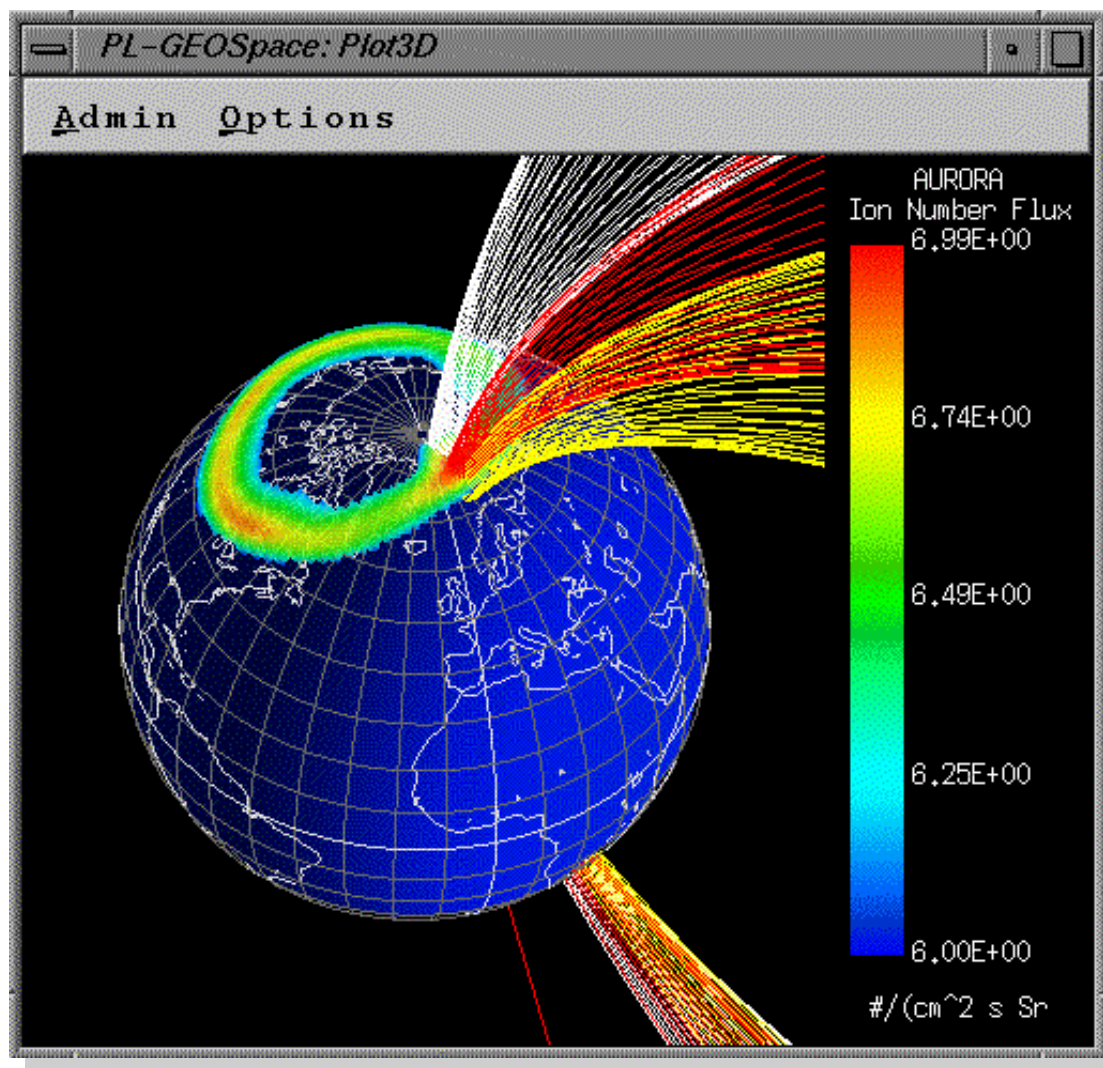




55 SWX Space Environment Product

HSUS9: Auroral Oval Analysis (Revised)

SATELLITE DESIGN AND ANOMALY RESOLUTION





SATELLITE DESIGN AND ANOMALY RESOLUTION

SRD RECOMMENDATIONS



40.8.13 Medium Energy Charged Particles Satellite Design and Anomaly Resolution

SATELLITE DESIGN AND ANOMALY RESOLUTION

Para. No.		Thresholds	Objectives
40.8.13-1	a. Horizontal Reporting Interval:	25 km	10 km
40.8.13-2	b. Measurement Range		
40.8.13-2.1	1. Energy:	50 keV - 10 MeV	
40.8.13-2.2	2. Total flux (m ² -s-ster) ⁻¹ :	10 ⁶ - 5x10 ¹¹	10 ⁵ - 5x10 ¹¹
40.8.13-2.3	3. Pitch Angle:	0° & 90°	0° & 90°
40.8.13-3	c. Measurement Precision		
40.8.13-3.1	1. Energy (low energy roll-off):	40%	40%
40.8.13-3.2	2. Total flux (m ² -s-ster) ⁻¹ :	5%	1%
40.8.13-3.3	3. Pitch Angle:	15°	15°
40.8.13-4	d. Measurement Accuracy		
40.8.13-4.1	1. Energy:	20%	10%
40.8.13-4.2	2. Total Flux (m ² -s-ster) ⁻¹ :	20%	10%
40.8.13-4.3	3. Pitch Angle:	10%	10%
40.8.13-5	e. Total Dose		
40.8.13-5.1	1. Range (rads/yr):		10 ¹ - 10 ⁶
40.8.13-5.2	2. Shielding thicknesses (mils Al):		4,100,250,500



40.8.14 Energetic Ions

Satellite Design and Anomaly Resolution

SATELLITE DESIGN AND ANOMALY RESOLUTION

Para. No.		Thresholds	Objectives
40.8.14-1	a. Horizontal Reporting Interval:	25 km	25 km
40.8.14-2	b. Measurement Range (p^+ & α^{++})		
40.8.14-2.1	1. Energy:	10 MeV - 300 MeV	10 keV - 400 MeV
40.8.14-2.2	2. Total flux ($m^2-s-ster$) $^{-1}$ p	$5 \times 10^3 - 2 \times 10^9$	$5 \times 10^3 - 2 \times 10^9$
40.8.14-2.3	3. Total flux ($m^2-s-ster$) $^{-1}$ alphas		$1 \times 10^2 - 1 \times 10^8$
40.8.14-2.3	3. Pitch Angle:	$\pm 60^\circ$	$\pm 90^\circ$
40.8.14-3	c. Measurement Precision		
40.8.14-3.1	1. Energy ($\Delta E/E$ or roll-off):	40%	40%
40.8.14-3.2	2. Total flux ($m^2-s-ster$) $^{-1}$:	5%	1%
40.8.14-3.3	3. Pitch Angle:	15%	15%
40.8.14-4	d. Measurement Accuracy		
40.8.14-4.1	1. Energy:	20%	10%
40.8.14-4.2	2. Total Flux ($m^2-s-ster$) $^{-1}$:	20%	10%
40.8.14-4.3	3. Pitch Angle:	10%	5%
40.8.14-5	e. Linear Energy Transfer (Heavy ions)		
40.8.14-5.1	1. Range (MeV cm^2-mg^{-1})		$1 \times 10^{-3} - 5 \times 10^{+1}$



40.8.16 Supra-Thermal / Auroral Particles Satellite Design and Anomaly Resolution

SATELLITE DESIGN AND ANOMALY RESOLUTION

Para. No.		Thresholds	Objectives
40.8.16-1	a. Horizontal Reporting Interval:	10 km	5 km
40.8.16-2	c. Measurement Range (e^- & p^+)		
40.8.16-2.1	1. Energy:	30 eV - 50 keV	30 eV - 50 keV
40.8.16-2.2	2. Total flux (m^2 -s-ster-keV) $^{-1}$:	$10^8 - 10^{15}$	$10^8 - 10^{15}$
40.8.16-2.3	3. Pitch Angle:	0° & 90°	$0^\circ - 90^\circ$
40.8.16-3	d. Measurement Precision		
40.8.16-3.1	1. Energy ($\Delta E/E$):	20%	10%
40.8.16-3.2	2. Total flux:	5%	1%
40.8.16-3.3	3. Pitch Angle:	$\pm 15^\circ$	$\pm 15^\circ$
40.8.16-4	e. Measurement Accuracy		
40.8.16-4.1	1. Energy:	10%	5%
40.8.16-4.2	2. Total Flux:	10%	5%
40.8.16-4.3	3. Pitch Angle:	10%	10%



Objective Measurements in SRD (Radiation Dose & Linear Energy Transfer)

SATELLITE DESIGN AND ANOMALY RESOLUTION

Radiation Dose

- Purpose - Provide quasi-continuous monitor of the van-Allen radiation belts.
- Rationale - Useful in assessing overall degradation in space power systems, materials, and sensors and identifying sources for electronic component logic upsets and failures.
- Description - Provide dose and dose rate behind four shielding thicknesses of A, for example, 4, 100, 250, and 500 mils. Integration time of 8 seconds, Range of 10 rads/yr to 10 mrads/yr, accuracy of 20%.
- Options - GTO is the preferred orbit for direct measurements. Polar LEO provides background reference as an index only.

Linear Energy Transfer

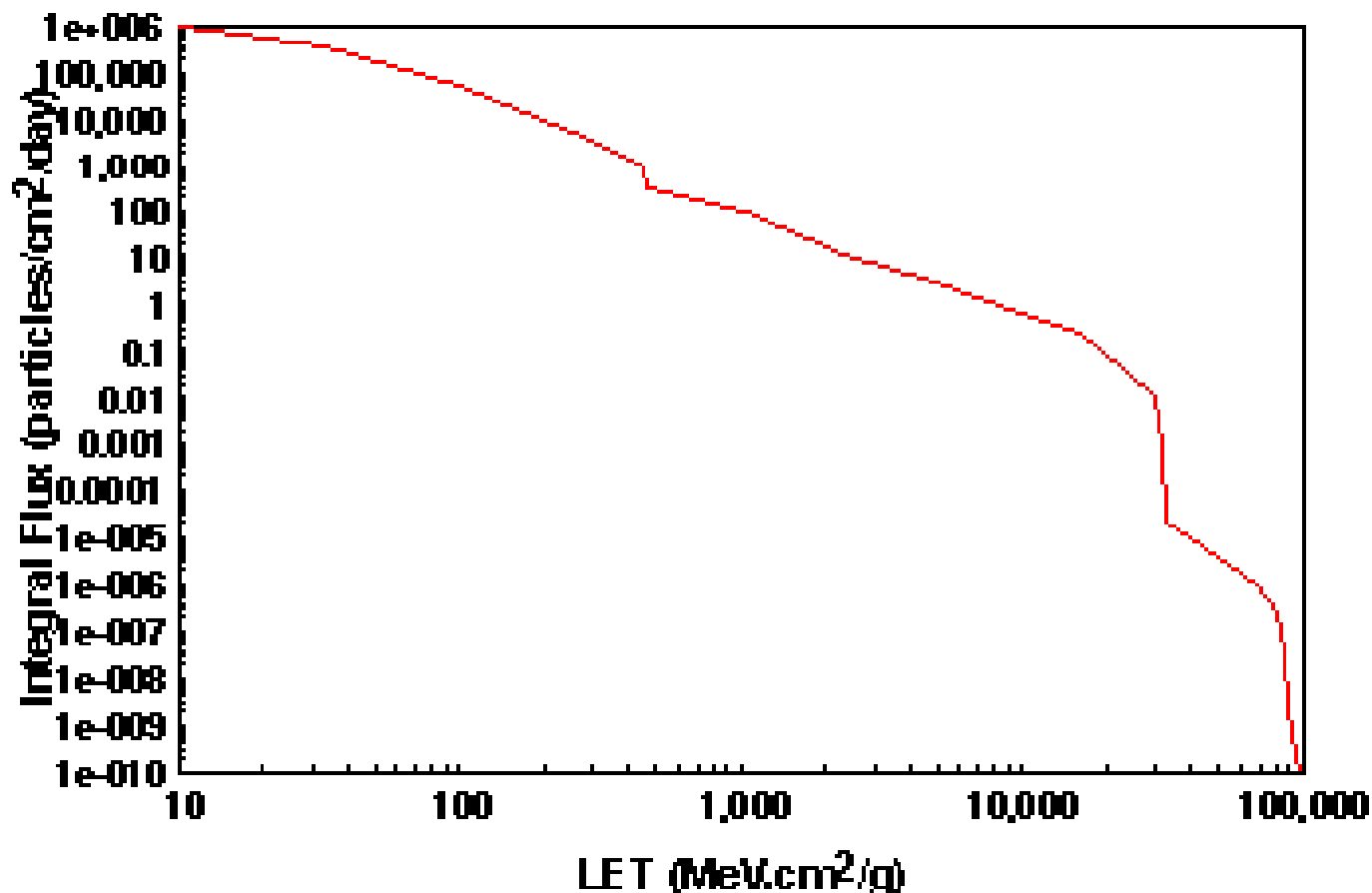
- Purpose - Provide quasi-continuous monitor of heavy ions in solar particle events.
- Rationale - Useful in assessing impacts to sensitive electronic components by heavy ions.
- Description - Provide integral flux ($\text{cm}^{-2} \text{ day}^{-1}$) versus L.E. T. for the range 1×10^{-3} to $5 \times 10^{+1} \text{ MeV cm}^2 \text{ mg}^{-1}$. Pulse height analysis of particles penetrating various shielding layers is used to derive an LET spectrum. Anticipated accuracy is 50%.
- Options - Requesting LET rather than energy-mass description results in a significant simplification to the NPOESS SES.



Objective Measurements in SRD (Radiation Dose & Linear Energy Transfer)

SATELLITE DESIGN AND ANOMALY RESOLUTION

An integral LET spectrum after 0.6mm Al
for 400km polar orbit





TASK 2: WG REPORTS

World Magnetic Model (Not really a Working Group)

Point of Contact

John Quinn, USGS

303 273-8475



World Magnetic Model Concept of Operations

Long-term Measurements

NPOESS
Magnetometer

Other Space
Data (DMSP,
Oersted, etc)

Surface
Data

World
Magnetic
Model
(WMM)

5-year Update

Field at Earth's Surface

North (X)	<140 nT
East (Y)	<140 nT
Vertical (Z)	<200 nT
Horizontal (H)	<200 nT
Intensity (F)	<280 nT
Declination (D)	<1°
Inclination (I)	<1°

Users:

Navigational
Guides
Attitude
Determination

MIL-W-89500
18 June 1993
OPR: NIMA



World Magnetic Model Data Requirements*

- **Vector Magnetometer**
 - Range: 60,000 nT (each axis)
 - Resolution/Sensitivity: < 2 nT/axis
 - Absolute Attitude Determination: <1 arc-min
 - Absolute Accuracy: <15 nT/axis
- **Scalar Magnetometer**
 - Range: 10,000 nT to 65,000 nT
 - Resolution/Sensitivity: <0.1 nT
- **Spacecraft Magnetic Noise**
 - At position of scalar/vector magnetometers: 15 nT
- **Other Parameters to be Monitored**
 - Vector Magnetometer's Sensor Temperature to within 0.1 °C
 - Vector Magnetometer's Electronics Temperature to within 0.1 °C
 - Scalar Magnetometer's Sensor Temperature to within 0.1 °C
 - Scalar Magnetometer's Electronics Temperature to within 0.1 °C
 - Solar Panel Current to within 0.1 A
 - Torquing Coils Current to within 0.1 A
 - Time & Duration of Data Transmission

* Measurement parameters as specified by the WMM OPR



BRIEFING OUTLINE

Background & Summary

Working Group Reports

→ Recommended IORD Changes¹

¹Definitions of terms contained on “notes” pages



EDR 4.1.6.7.1

Changes is *Red Italics*; Objective in (Parentheses)

Auroral Boundary

Measurement Accuracy	± 50 (± 10) km <i>± 100 (± 10) km</i>	IORD-1 <i>Recommendation</i>
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Justification:

- Regions that produce auroral clutter in radars have a scale size of $\sim 1^\circ$ (~ 111 km). To distinguish auroral clutter, the resolution of the auroral boundary determination must be at least this good.
- Requirement applies to equatorial boundary at all longitudes.



EDR 4.1.6.7.2

Changes is *Red Italics*; Objective in (Parentheses)

Auroral Energy Deposition (Total) \longrightarrow ***Auroral Energy Deposition***

Measurement Range	e ⁻	10 ⁻⁴ (5x10 ⁻⁵) to 1.0 W/m ²	IORD-1
	p ⁺	10 ⁻⁴ (5x10 ⁻⁵) to 10 ⁻¹ W/m ²	IORD-1
	<i>Energy Flux</i>	<i>10⁻⁴ (5x10⁻⁵) to 1.0 W/m²</i>	<i>Recommendation</i>
	<i>Mean Energy:</i>	<i>100 (30) eV to 20 (30) keV</i>	<i>Recommendation</i>
Measurement Accuracy	max[±10 ⁻⁴ (±5x10 ⁻⁵ W/m ²) W/m ² or ±20% (±10%)]		IORD-1

Justification:

- The precipitating auroral energy flux, in W/m², along the path of the satellite can be a direct measurement of the precipitating charged particles (see EDR 4.1.6.7.16, Supra-thermal through Auroral Energy Particles) or an inferred measurement based on optical emissions.
- Requirement is a localized or regional measurement which can be used to produce a global average or provide inputs to advanced space environment models.
- See the Web site at: “<http://www.sec.noaa.gov/hempower/index.html>”.
- Specification of precipitating charged particle species not required.



EDR 4.1.6.7.3

Changes is *Red Italics*; Objective in (Parentheses)

Auroral Imagery

Measurement Range	120 (80) to 180 (250) nm <i>Moderate (Quiet) to Very Active Aurora</i>	IOR-D-1 <i>Recommendation</i>
Measurement Accuracy	±10% (±5%)	IOR-D-1
Horizontal Resolution	20 (10) km <i>100 (10) km</i>	IOR-D-1 <i>Recommendation</i>

Justification:

- Specific wavelength range for Measurement Range represents a particular sensor. Intensities are dependent on the auroral emissions to be measured. It should be left up to the contractor to recommend a particular sensor solution in these areas. Statistical models of auroral emissions can be used by the contractor to determine Measurement Range and Measurement Accuracies.
- Statistically dimmer auroral features can be ignored as a threshold since they have minimal impact on radar systems.
- Measurement accuracy refers to signal amplitude.
- Reference, Table 12-2, in *Handbook of Geophysics and the Space Environment*, edited by A.S. Jursa, AFGL, ADA-167000 (NTIS), 1985.



EDR 4.1.6.7.4

Changes is *Red Italics*; Objective in (Parentheses)

Electric Field

Measurement Range	0 to 150 (250) mV/m 0 to <i>±150 (± 250)</i> mV/m	IORD-1 <i>Recommendation</i>
Measurement Precision	2 (0.1) mV/m	IORD-1
Measurement Accuracy	±3 (±0.1) mV/m	IORD-1

Justification:

- Full vector quantity. EDR 4.1.6.7.7, In-situ Drift Velocity, has been subsumed into this EDR. In the horizontal plane (perpendicular to B), the *convective* drift and the electric field are the same (after correcting for earth co-rotation).
- Along B the diffusive outflow of plasma is not accompanied by a measurable electric field. Measurement of this flow is an objective measurement.
- Changes are driven by requirements for both auroral and equatorial electric fields. Measurement ranges (threshold and objective), accuracy (threshold), and precision (threshold) are auroral requirements. Objective values for accuracy and precision used for low-latitude scintillation prediction.



EDR 4.1.6.7.5 (1 of 2)

Changes is *Red Italics*; Objective in (Parentheses)

Electron Density Profiles / Ionospheric Specification

Horizontal Resolution

1. 0° to 30° Lat.	200 (100) km	IORD-1
2. 30° to 50° Lat.	500 (250) km	IORD-1
3. 50° to 90° Lat.	100 (50) km	IORD-1

Vertical Resolution

1. Within 100 km of either the E-layer or F-layer peaks	10 (5) km	IORD-1
2. Elsewhere	20 (5) km	IORD-1

Measurement Range

1. Local density	3×10^5 (10^4) to 10^7 cm ⁻³	IORD-1
2. TEC	3×10^{16} (10^{16}) to 2×10^{18} m ⁻²	IORD-1
3. f_oF_2	5 (1) to 30 MHz	IORD-1

Measurement Accuracy

1. Local density	$\pm 3 \times 10^5$ ($\pm 1 \times 10^4$) cm ⁻³	IORD-1
2. NmF2	$\pm 20\%$ ($\pm 5\%$)	IORD-1
3. HmF2	$\pm 20\%$ ($\pm 5\%$)	IORD-1
4. TEC	max[$\pm 20\%$ or $\pm 3 \times 10^{16}$ ($\pm 1 \times 10^{16}$) m ⁻²]	IORD-1



EDR 4.1.6.7.5 (2 of 2)

Changes is *Red Italics*; Objective in (Parentheses)

Electron Density Profile

Horizontal Resolution	<i>0-to-30° Lat</i>	<i>100 (10) km</i>	<i>Recommendation</i>
	<i>30-to-50° Lat</i>	<i>500 (250) km</i>	<i>IORD-1</i>
	<i>50-to-90° Lat</i>	<i>50 (10) km</i>	<i>Recommendation</i>
Vertical Resolution	<i>90-to-500 km</i>	<i>10 (3) km</i>	<i>Recommendation</i>
	<i>500-to-800 (1600) km</i>	<i>20 (5) km</i>	<i>Recommendation</i>
Measurement Range	1. n_e	<i>3×10^4 (10^4) to 10^7 cm⁻³</i>	<i>Recommendation</i>
	2. VTEC	3 (1) to 200 TEC units	<i>Recommendation</i>
Measurement Uncertainty	1. n_e	<i>max [$\pm 10^5$ ($\pm 10^4$) cm⁻³ or $\pm 30(\pm 5)\%$]</i>	<i>Recommendation</i>
	2. VTEC	<i>max [± 3 (1) TEC or $\pm 30\%$]</i>	<i>Recommendation</i>
<i>Threshold Features: $h_m F_2$ @ $\pm 20(5)$ km, $N_m F_2$ @ $\pm 20(\pm 10\%)$, $N_m E$ @ $\pm 20(\pm 5)\%$ Recommendation</i>			
<i>Note: In-situ ion composition ($\pm 5\%$ per species) is an objective.</i>			

Justification:

- CONOPS details imply different accuracies for profile features in different geographic regions. See Ionospheric WG briefing for details (see “notes”).
- Revised n_e threshold value (range) driven by VTEC threshold (range)



EDR 4.1.6.7.6

Changes is *Red Italics*; Objective in (Parentheses)

Geomagnetic Field

In-track Resolution	10 (0.5) km <i>1.0(0.1 km)</i>	IORD-1 <i>Recommendation</i>
Measurement Range	20,000(10,000) - 60,000 nT <i>0 to ±60,000 nT</i>	IORD-1 <i>Recommendation</i>
Measurement Precision	2 (0.5) nT <i>6 (2) nT</i>	IORD-1 <i>Recommendation</i>
Measurement Accuracy		
Magnitude	±6 (±2) nT <i>±17 nT</i>	IORD-1 <i>Recommendation</i>
Vector Direction	1 (0.6) arc min	IORD-1

Justification:

- Full vector quantity. Continuous global sampling is required.
- Sample & hold for the component measurement must be commensurate with a 100-m POD; that is, a sample & hold time of less than 13 ms.
- Calibration of the vector magnetometer may require an accurate (0.1 nT) scalar magnetometer.
- WMM POC is J. Quinn (USGS/303 273-8475).



EDR 4.1.6.7.7

Changes is *Red Italics*; Objective in (Parentheses)

In-situ Ion Drift Velocity

Measurement Range	0 to 3 (5) km/s	IORD-1
Measurement Accuracy	± 75 (± 50) m/s	IORD-1
Measurement Precision	50 (25) m/S	IORD-1

Justification:

- Deleted. Reference EDR 4.1.6.7.4. Electric Field. In-situ Ion Drift Velocity has been subsumed into EDR 4.1.6.7.4.

MERGED EDR



EDR 4.1.6.7.8

Changes is *Red Italics*; Objective in (Parentheses)

In-situ Plasma Density

In-track Resolution	50 (10) km	IORD-1
Measurement Range	5×10^3 (1×10^2) to 5×10^6 (1×10^7)	IORD-1
Measurement Accuracy	$\pm 20\%$ ($\pm 5\%$)	IORD-1

Justification:

- Deleted. Rolled-up under EDR 4.1.6.7.5 and EDR 4.1.6.7.9. In-situ plasma density measurements may be required to normalize remote sensing data for measurement accuracy and spatial resolution.

MERGED EDR



EDR 4.1.6.7.9

Changes is *Red Italics*; Objective in (Parentheses)

In-situ Plasma Fluctuations

In-track Resolution	100 km (5 m) 100 <i>(50) km</i>	IORD-1 <i>Recommendation</i>
Measurement Range		
1. Spectral Index	2 (1) to 5 (10) <i>1</i> to 5	IORD-1 <i>Recommendation</i>
2. $\Delta n/n$	10^{-2} (10^{-4}) to 1.0 10^{-2} to 1.0	IORD-1 <i>Recommendation</i>
<i>Measurement Accuracy</i>		
<i>1. Mean Density</i>	<i>20% (5)%</i>	<i>Recommendation</i>

Justification:

- Resolution threshold can be relaxed to match minimum size of scintillation regions. Former 5-m objective was in error and referred to the sample rate associated with determining the spectral index and $\Delta n/n$. The reported quantities are not required at this resolution.
- Spectral indices above 5 do not naturally occur.
- Low-level fluctuations do not adversely impact operational systems.
- Absolute in-situ amplitude fluctuations levels (the same as knowing the mean density) are needed to estimate L- and S-band scintillation levels.



EDR 4.1.6.7.10

Changes is *Red Italics*; Objective in (Parentheses)

In-situ Plasma Temperature (T_i & T_e)

In-track Resolution	100 (10) km	IORD-1
Measurement Range	500 to 10,000 °K	IORD-1
Measurement Accuracy	$\pm 10\%$ ($\pm 5\%$)	IORD-1

Justification:

- No comment - OK



EDR 4.1.6.7.11

Changes is *Red Italics*; Objective in (Parentheses)

Ionospheric Scintillation

Horizontal Resolution	100 (50) km	IORD-1
Measurement Range		
1. Amplitude Index (S4)	0.1 to 1.5	IORD-1
2. Phase Index (sigma-phi)	0.1 to 20 rad	IORD-1
Measurement Precision		
1. Amplitude Index (S4)	0.1 <i>delete</i>	IORD-1 <i>Recommendation</i>
2. Phase Index (sigma-phi)	0.1 rad <i>delete</i>	IORD-1 <i>Recommendation</i>
Measurement Accuracy	factor of 2	IORD-1
1. <i>Amplitude Index (S4)</i>	<i>0.1</i>	<i>Recommendation</i>
2. <i>Phase Index (sigma-phi)</i>	<i>0.1 rad</i>	<i>Recommendation</i>

Justification:

- Measurement Range (Threshold) spans total range of naturally occurring values. There is no need for an Objective range.
- Measurement accuracy does not apply to the specification for scintillation. The factor of 2 is a hold-over from an earlier version of the document.
- Specification of impact to applicable frequency bands desired: L-band, S-band, VHF, UHF



EDR 4.1.6.7.12

Changes is *Red Italics*; Objective in (Parentheses)

Neutral Density Profile/Neutral Atmospheric Specification

—————→ *Neutral Density Profile*

Sensing Depth	100 (90) to 750 (1600) km <i>90 - 800</i> (1600) km	IORD-1 <i>Recommendation</i>
In-track Resolution	500 (50) km 500 <i>(250)</i> km	IORD-1 <i>Recommendation</i>
Vertical Resolution	10 (0.5) km for <120 km; 10 (3) km for >120 km) <i>5</i> (0.5) km for <120 km; <i>5 (3) km</i> for >120 km)	IORD-1 <i>Recommendation</i>
Measurement Range:		
Mass density:	3×10^{-9} to 2×10^{-19} g/cm ³	IORD-1
Number density:	6×10^{13} to 9×10^{14} cm ⁻³	IORD-1
Measurement Accuracy	$\pm 15\%$ ($\pm 5\%$) for altitudes: <500 km <i>$\pm 10\%$</i> ($\pm 5\%$) for altitudes: <500 km $\pm 20\%$ ($\pm 10\%$) for altitudes: 500 < 700 km <i>$\pm 15\%$</i> ($\pm 10\%$) for altitudes: 500 < 700 km $\pm 20\%$ ($\pm 15\%$) for altitudes :>700 km <i>$\pm 20\%$ ($\pm 15\%$)</i> for altitudes: > 700 km	IORD-1 <i>Recommendation</i> IORD-1 <i>Recommendation</i> IORD-1 <i>Recommendation</i>

Note: In-situ composition added as an objective measurement.

Justification:

- Provides consistency to USSPACECOM requirement, re-validated JUN-97 see “notes”



EDR 4.1.6.7.13

Changes is *Red Italics*; Objective in (Parentheses)

Radiation Belt & Low Energy Solar Particles

→ *Medium Energy Charged Particles*

	ENERGY	FLUX	
Measurement Range	30 keV - 10 MeV (e ⁻ & p ⁺)	10 ⁵ - 10 ¹¹ /m ² -s-ster	IORD-1
	<i>p⁺ 50 keV - 10 MeV</i>	<i>10⁶ - 5(20)x10¹¹ /m²-s-ster</i>	<i>Recommendation</i>
	<i>e⁻ 50 keV - 1 MeV (10 MeV)</i>	<i>10⁶ - 5(20)x10¹¹/m²-s-ster</i>	<i>Recommendation</i>
Measurement Precision	8 energy bands	5% (1%)	IORD-1
	<i>6 energy bands</i>	<i>5% (1%)</i>	<i>Recommendations</i>
Measurement Accuracy		20% (10%)	IORD-1

Note: Total dose left as objective measurement.

Justification:

- Low energy range covered by the supra-thermal through auroral energy EDR. In addition, raising the low energy threshold from 30 keV to 50 keV simplifies sensor design and reduces radiation damage.
- Upper flux (threshold) set by experience from the TIROS satellite. Lower bound set by typical dynamic ranges for solid state detectors and the total flux precision requirement
- Reduced # of energy bands simplifies instrument design.



EDR 4.1.6.7.14

Changes is *Red Italics*; Objective in (Parentheses)

Solar & Galactic Cosmic Ray Particle → *Energetic Ions*

		ENERGY	FLUX	
Measurement	protons	>10 - (>)1000 MeV/nucleon	$10^3 (10^2) - 10^{10} / \text{m}^2\text{-s-ster}$	IODR-1
Range	alpha	>10 - (>)1000 MeV/nucleon	$10^2 - 10^8 / \text{m}^2\text{-s-ster}$	IODR-1
	CNO	>10 - 100 MeV/nucleon	$10^0 - 10^7 / \text{m}^2\text{-s-ster}$	IODR-1
	Fe	>10 - 100 MeV/nucleon	$10^{-1} (10^{-3}) - 10^6 / \text{m}^2\text{-s-ster}$	IODR-1
	<i>protons</i>	<i>10 MeV - 300 MeV (400 MeV)</i>	<i>$5 \times 10^3 - 2 \times 10^9 / \text{m}^2\text{-s-ster}$</i>	<i>Recommendation</i>
Measurement	protons	6 (8) bands	5% (1%)	IODR-1
Precision	alpha	6 (8) bands	5% (1%)	IODR-1
	CNO	4 bands	5% (1%)	IODR-1
	Fe	4 bands	5% (1%)	IODR-1
	<i>protons</i>	<i>6 (8) bands</i>	<i>5% (1%)</i>	<i>Recommendation</i>
Measurement	Accuracy		20% (10%)	IODR-1

Note: Linear energy transfer (L.E.T.) left as an objective measurement: $[1(0.1) - 50(100) \text{ MeV cm}^2 \text{ mg}^{-1}]$

Justification:

- Sharply reduced levels of energetic protons exist above 100 MeV.
- Flux range is compatible with modest-to-high event levels.
- **NOTE**: Alphas and heavy ions are left as objective measurements.



EDR 4.1.6.7.15

Changes is *Red Italics*; Objective in (Parentheses)

Solar Extreme Ultra Violet Flux

Measurement Range	5 (1) to 130 (175) nm in 4 (10) channels <i>4 (12) wavelength bands, covering the region 5 (10) to 130 (175) nm: 0.0001 - 0.0200 W/m² Lyman Alpha: 0.0010 - 0.0200 W/m²</i>	IOR-D-1 <i>Recommendation</i>
Measurement Accuracy	max[$\pm 10^{-4}$ ($\pm 5 \times 10^{-5}$) W/m ² or $\pm 20\%$ ($\pm 10\%$)] <i>$\pm 10\%$ ($\pm 5\%$)</i>	IOR-D-1 <i>Recommendation</i>

Justification:

- The range specified should cover a solar flux range, in addition to the bands required to measure this flux range. The wavelength bands are referenced in “Space Environmental Monitoring Requirements for Polar Orbiting Spacecraft”. The EUV heating of the upper atmosphere is a function of the product of the EUV flux per wavelength interval and the interval-averaged cross sections summed over the EUV spectrum. The wavelength intervals were chosen to optimize the correspondence between large cross sections and strong flux features.
- The accuracy was derived from the threshold and objective operational density requirements based on the sensitivity of heating to EUV fluxes and the sensitivity of density to heating.



EDR 4.1.6.7.16

Changes is *Red Italics*; Objective in (Parentheses)

Supra-thermal through Auroral Energy Particles

	ENERGY	FLUX	
Measurement	30 eV - 30 keV	$10^8 - 10^{15} / \text{m}^2\text{-s-ster-keV}$	IORD-1
Range	30 eV - <i>50 keV (100 keV)</i>	$10^8 - 10^{15} / \text{m}^2\text{-s-ster-keV}$	<i>Recommendation</i>
Measurement Precision	20% (10%)	5% (1%)	IORD-1
Measurement Accuracy		$\pm 20\%$ ($\pm 10\%$)	IORD-1

Justification:

- Recent findings indicate that auroral electrons of up to 50 keV are responsible for charging of LEO satellites. Reference: Anderson et al., 1996.



EDR 4.1.6.7.17

Changes is *Red Italics*; Objective in (Parentheses)

Upper Atmospheric Airglow

In Track Resolution (Limb)	750 (100 km) km	IORD-1
Horiz. Resolution (Disk):		
0° to 30° Lat	200 (100) km	IORD-1
	<i>100 (10) km</i>	<i>Recommended</i>
30° to 50° Lat	500 (250) km	IORD-1
50° to 90° Lat	100 (10) km	IORD-1
	<i>50 (10) km</i>	<i>Recommended</i>
Vert. Resolution (Limb)	20 (5) km	IORD-1
Measurement Range		
Limb, at 8-14 nm	20 (1) to 1000 R	IORD-1
	<i>20 (10) to 3000 (5000) R</i>	<i>Recommended</i>
Limb, at 135.6 nm	0.2 (0.1) to 10 R	IORD-1
	<i>0.02 (0.5) to 10 (20) kR</i>	<i>Recommended</i>
Limb, at 140 to 180 nm	0.2 (0.1) to 10 R	IORD-1
Disk, at 12-16 nm	1 (0.1) to 3 kR	IORD-1
	<i>1 (0.5) to 10 (30) kR</i>	<i>Recommended</i>
Disk, at 135.6 nm	1 (1) to 4000 R	IORD-1
	<i>5 (0.5) to 3000 (6000) R</i>	<i>Recommended</i>
Disk, at 140 to 180 nm	4 (1) to 5000 R	IORD-1
	<i>10 (5) to 3000 (6000) R</i>	<i>Recommended</i>
Meas. Accuracy	±10 (±5 %) %	IORD-1

Justification:

- Airglow measurements is a solution to determining EDP & NDP



PROPOSED EDR

Changes is *Red Italics*; Objective in (Parentheses)

Neutral Winds - Objective EDR

<i>Horizontal Resolution</i>	<i>200 (10) km</i>	<i>Recommendation</i>
<i>Horizontal Coverage</i>	<i>0°-30°, 50°-90° (global) magnetic N & S</i>	<i>Recommendation</i>
<i>Vertical Coverage</i>	<i>200 to 400 km</i>	<i>Recommendation</i>
<i>Vertical Resolution</i>	<i>20 (10) km</i>	<i>Recommendation</i>
<i>Measurement Range</i>	<i>±300 (±1500) m/s</i>	<i>Recommendation</i>
<i>Measurement Accuracy</i>	<i>max[±10% (±5) % or 20 (5) m/s]</i>	<i>Recommendation</i>

Justification:

- Neutral winds is a determining factor in the generation of equatorial scintillation (threshold). Neutral winds also play an important role in first-principles thermospheric models (objective).
- The drag force is related to the velocity of the satellite (or debris) relative to the wind velocity. At high latitudes during disturbed conditions winds can be a 20 % effect relative to no-wind conditions.